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DEPARTMENT OF ENERGY**

**THE IMPACT OF ENTRAINMENT  
AND IMPINGEMENT ON FISH  
POPULATIONS IN THE  
HUDSON RIVER ESTUARY**

**VOLUME II**

**Impingement Impact Analyses,  
Evaluations of Alternative  
Screening Devices, and  
Critiques of Utility Testimony  
Relating to Density-Dependent  
Growth, the Age-Composition  
of the Striped Bass Spawning  
Stock, and the LMS Real-Time  
Life Cycle Model**

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ENVIRONMENTAL SCIENCES DIVISION  
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Dependent Growth, the Age-Composition of the Striped Bass  
Spawning Stock, and the LMS Real-Time Life Cycle Model

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TASK: Methods to Assess Impacts on Hudson River Striped Bass

OAK RIDGE NATIONAL LABORATORY  
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for the  
DEPARTMENT OF ENERGY



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## FOREWORD

On December 19, 1980, with the signing of an out-of-court settlement agreement, a three-year adjudicatory hearing on the effects of electric power generation on the Hudson River was ended. The purpose of this hearing had been to determine whether six cooling towers, required by the various Environmental Protection Agency (EPA) permits, should be built at three power plants on the Hudson River in New York in order to mitigate the impacts of entrainment and impingement on estuarine fish populations. In addition to terminating the EPA hearings, the settlement resolved regulatory disputes between the utility companies and several other federal agencies, including the U.S. Nuclear Regulatory Commission (NRC).

Staff of the Environmental Sciences Division at Oak Ridge National Laboratory (ORNL) were asked to participate in the EPA hearings because of previous work on entrainment and impingement performed for AEC, NRC, ERDA, and DOE in connection with the licensing of Indian Point Units 2 and 3, the largest generating units on the Hudson River. ORNL Staff prepared and submitted, in May 1979, numerous individual pieces of written direct testimony for EPA as part of these hearings. Some of these pieces of testimony were coauthored with individuals from the National Power Plant Team of the U. S. Fish and Wildlife Service and from EPA. The purpose of this three-volume report is to publish these individual pieces of testimony involving ORNL staff in a manner that will assure a broader distribution to the scientific community, government agencies, and other interested parties.

Volume I is concerned with the estimation of the direct (or annual) entrainment impact of the power plants on populations of striped bass, white perch, Alosa spp. (blueback herring and alewife), American shad, Atlantic tomcod, and bay anchovy in the Hudson River. Entrainment impact results from the killing of fish eggs, larvae, and young juveniles that are contained in the cooling water cycled through a power plant. An "Empirical Transport Model" is presented as the means of obtaining a conditional entrainment mortality rate (which represents the fraction of a year class which would be killed due to entrainment in the absence of density-dependent mortality). Most of Volume I is concerned with the estimation of several parameters required by the model: physical input parameters (e.g., power-plant withdrawal flow rates); the longitudinal distribution of ichthyoplankton in time and space; the duration of susceptibility of the vulnerable organisms; the "W-factors," which express the ratios of densities of organisms in power plant intakes to densities in the river; and the entrainment mortality factors, which express the probability that an organism will be killed if it is entrained. Once these values are obtained, the model is used to estimate entrainment impact for both historical conditions and projected conditions.

Volume II contains four exhibits relating to impingement impacts and three critiques of certain aspects of the utilities' case. The first exhibit is a quantitative evaluation of four sources of bias (collection efficiency, reimpingement, impingement on inoperative screens, and impingement survival) affecting estimates of the number of fish killed at Hudson River power plants. The two following exhibits contain, respectively, a detailed assessment of the impact of impingement on the Hudson River white perch population and estimates of conditional impingement mortality rates for seven Hudson River fish populations. The fourth exhibit is an evaluation of the engineering feasibility and potential biological effectiveness of several types of modified intake structures proposed as alternatives to cooling towers for reducing impingement impacts. The remainder of Volume II consists of critical evaluations of the utilities' empirical evidence for the existence of density-dependent growth in young-of-the-year striped bass and white perch, of their estimate of the age-composition of the striped bass spawning stock in the Hudson River, and of their use of the Lawler, Matusky, and Skelly (LMS) Real-Time Life Cycle Model to estimate the impact of entrainment and impingement on the Hudson River striped bass population.

Volume III addresses the validity of the utilities' use of the Ricker stock-recruitment model to extrapolate the combined entrainment-impingement losses of young fish to reductions in the equilibrium population size of adult fish. In our testimony, a methodology was developed and applied to address a single fundamental question: if the Ricker model really did apply to the Hudson River striped bass population, could the utilities' estimates, based on curve-fitting, of the parameter alpha (which controls the impact) be considered reliable? The present Volume III includes, in addition, an analysis of the efficacy of an alternative means of estimating alpha, termed the technique of prior estimation of beta (used by the utilities in a report prepared for regulatory hearings on the Cornwall Pumped Storage Project). Our validation methodology should also be useful in evaluating inferences drawn in the literature from fits of stock-recruitment models to data obtained from other fish stocks.

## ABSTRACT

BARNTHOUSE, L. W., W. VAN WINKLE, J. GOLUMBK, G. F. CADA, C. P. GOODYEAR, S. W. CHRISTENSEN, J. B. CANNON, and D. W. LEE. 1982. Impingement impact analyses, evaluations of alternative screening devices, and critiques of Utility testimony relating to density-dependent growth, the age-composition of the striped bass spawning stock, and the LMS Real-Time Life Cycle Model. Volume II. IN The Impact of Entrainment and Impingement on Fish Populations in the Hudson River Estuary. ORNL/NUREG/TM-385/V2 and NUREG/CR-2220. Oak Ridge National Laboratory, Oak Ridge, Tennessee.

This volume includes a series of four exhibits relating to impacts of impingement on fish populations, together with a collection of critical evaluations of testimony prepared for the utilities by their consultants. The first exhibit is a quantitative evaluation of four sources of bias (collection efficiency, reimpingement, impingement on inoperative screens, and impingement survival) affecting estimates of the number of fish killed at Hudson River power plants. The two following exhibits contain, respectively, a detailed assessment of the impact of impingement on the Hudson River white perch population and estimates of conditional impingement mortality rates for seven Hudson River fish populations. The fourth exhibit is an evaluation of the engineering feasibility and potential biological effectiveness of several types of modified intake structures proposed as alternatives to cooling towers for reducing impingement impacts. The remainder of Volume II consists of critical evaluations of the utilities' empirical evidence for the existence of density-dependent growth in young-of-the-year striped bass and white perch, of their estimate of the age-composition of the striped bass spawning stock in the Hudson River, and of their use of the Lawler, Matusky, and Skelly (LMS) Real-Time Life Cycle Model to estimate the impact of entrainment and impingement on the Hudson River striped bass population.



## SUMMARY

The first four chapters in this volume relate to impacts of impingement on Hudson River fish populations. In Chapter I, the utilities' estimates of the numbers of fish impinged at the Bowline, Lovett, Indian Point, Roseton, and Danskammer generating stations are evaluated. The methods used to compute the number of fish killed by impingement at each of these plants are described, and four sources of bias that can affect impingement estimates (collection efficiency, reimpingement, impingement on inoperative travelling screens, and impingement survival) are discussed. Wherever possible, the magnitude of each bias is estimated. Finally, plant and species-specific adjustment factors that can be used to scale the impingement estimates up or down to account for these biases are presented.

Chapter II presents two independent lines of evidence evaluating impingement losses of white perch at the power plants on the Hudson River. The first line of evidence involves analyzing the variation in collection rates among years over the period 1972-1977. These rates provide estimates of year-class strength on a relative scale. The second line of evidence involves estimating the conditional mortality rate (or equivalently, the percent reduction in year-class strength in the absence of compensation) due to impingement for the 1974 and 1975 white perch year classes.

Chapter III presents estimates of conditional impingement mortality rates for the 1974 year classes of white perch, striped bass, alewife, blueback herring, American shad, and Atlantic tomcod, and for the 1975 year classes of white perch, striped bass, American shad, and the Atlantic tomcod. Exploitation rates for the total impingeable bay anchovy population (adults + juveniles) residing above river mile 12 are presented for each month from May through October 1974 and 1975. Rather than single "conservative" estimates of impact, realistic ranges of probable impacts for each species and year class are developed. The highest impingement impact estimates obtained are for white perch, the lowest for American shad. In addition to estimates of actual historical impacts, estimates of the impacts that would have occurred had closed-cycle cooling systems been installed at one or more of the three plants (Bowline, Indian Point, and Roseton) at issue in the hearings, are presented. It was found that greatly reduced impacts on white perch, Atlantic tomcod, and striped bass would have occurred had closed-cycle cooling systems been operating either at all three plants or only at Bowline and Indian Point. Closed-cycle cooling at Indian Point alone would have substantially reduced the impact of impingement on white perch and Atlantic tomcod, and would have moderately reduced the impact on striped bass.

Chapter IV presents evaluations of the degree to which impingement and entrainment mortality at the intake screenwells of Indian Point Units 2 and 3, Bowline, and Roseton, can be potentially reduced by

backfitting them with alternative screening devices. Both physical and behavioral screening barriers are considered. The physical screening barriers considered are (1) conventional vertical traveling screens (VTS) with modifications, (2) center-flow traveling screens, (3) flush-mounted horizontal traveling screens (HTS), (4) cylindrical wedge-wire screens, and (5) radial well intakes. The behavioral screening barriers considered are angled HTS and louver and angled screen diversion systems. It is concluded that there are alternative devices available that could potentially reduce impingement and, to a lesser extent, extrainment mortality at power plant cooling-water intakes. The extent of reduction achievable in practice however, is site specific and can best be determined from in situ studies during plant operation.

Chapter V presents a critical evaluation of empirical "evidence" for the existence of density-dependent growth in the Hudson River striped bass and white perch populations. Consultants for the utilities have, on several occasions, reported finding inverse correlations between growth and abundance in juvenile striped bass and white perch, and have cited these results as evidence that density-dependent growth, a compensatory mechanism capable of partially offsetting the impact of power plant entrainment and impingement, may be operating in the Hudson River striped bass and white perch populations. An evaluation of the data and methods of analysis used by the utilities' consultants shows that it is not possible to demonstrate the existence or non-existence of density-dependent growth from existing data. It is further argued that, even if the existence of density-dependent growth could be proved, knowledge of its existence would be useless to the decision-maker because its compensatory effects cannot be quantified.

Chapter VI presents a critical analysis of the utilities' estimate of the age-composition of the striped bass spawning stock in the Hudson River. Estimates of the contribution of each age-class to each year's production are used by the utilities to develop lag times that determine the pairing of indices of stock and recruitment in their Ricker stock-recruitment curve-fitting exercise (Volume III). The estimates of long-term power plant impact obtained from the curve-fitting exercise are highly sensitive to the choice of lag time. It is concluded that the utilities greatly underestimated the contribution of age seven and older striped bass to the spawning stock, thereby underestimating the proper lag time for the stock-recruitment analysis.

Chapter VII presents an evaluation of the utilities' use of the LMS Real-Time Life Cycle Model to estimate reductions in year-class abundance of striped bass caused by entrainment and impingement. It is concluded that the Real-Time Life Cycle Model is not a reliable tool for making sound fisheries management decisions.

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CHAPTER I

AN ANALYSIS OF FACTORS THAT INFLUENCE IMPINGEMENT ESTIMATES  
AT HUDSON RIVER POWER PLANTS

TESTIMONY OF

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## SUMMARY

In this testimony I evaluate the utilities' estimates of the numbers of fish impinged at the Bowline, Lovett, Indian Point, Roseton, and Danskammer generating stations. I describe the methods used to compute the number of fish killed by impingement at each of these plants and discuss four sources of bias that can affect impingement estimates: collection efficiency, reimpingement, impingement on inoperative travelling screens, and impingement survival. Wherever possible I estimate the magnitude of each bias. Finally, I present plant and species-specific adjustment factors that can be used to scale the impingement estimates up or down to account for these biases.



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## 1. INTRODUCTION

In order to facilitate understanding of my assessment of this aspect of the utilities' case, I begin with a brief outline of the data, methods, and biases involved in computing the number of fish impinged and killed by a power plant. I describe each component of the computational procedure and identify those components in which there is a substantive disagreement between my position and that taken by the utilities and their consultants. These disagreements are discussed in detail in Section 2.

At first glance it seems that there should be no substantive disagreements as to the number of fish that are impinged at Hudson River power plants. All one has to do is collect and count the fish that are washed off the travelling screens. However, the problem is not quite that simple. Only at Indian Point are attempts made to collect and count all fish that are washed off the screens. At all other plants the screenwash is sampled once or twice a week (usually for 24 hours), and the resulting counts are scaled up to arrive at weekly and/or monthly estimates of the numbers of fish impinged. Moreover, the raw counts of fish impinged at any plant are subject to several sorts of biases that can lead to overestimates or underestimates of the true number of fish killed by impingement. First, not all impinged fish are actually collected. A certain percentage, highly variable from plant to plant, are washed off the screens back out into the river, or are eaten by scavengers. Since these fish are not collected, they are not included in the impingement counts. Second, at plants where impinged fish are sampled only periodically, the same fish may be impinged more than once, inflating the impingement counts. Third, at some plants fish may be impinged on inoperative travelling screens and thus not collected or counted. Finally, for some species at some plants, a substantial fraction of impinged fish may survive impingement if they are promptly returned to the river. All of these potential biases must be considered in order to assess the reliability of impingement estimates and in order to determine whether (and by how much) these estimates must be adjusted.

Since I believe that the impingement totals used in calculating conditional impingement mortality rates should reflect impingement at all plants, not just at those that are the subject of these proceedings, I evaluate the impingement estimates for Lovett, Danskammer, and Albany along with those for Bowline, Indian Point, and Roseton.

### 1.1 HOW IMPINGEMENT ESTIMATES ARE CALCULATED

At Indian Point Units 1, 2, and 3, all (or nearly all) screenwashes are monitored and attempts are made to collect, identify, and count all impinged fish. At all other plants the screenwashes are monitored for 24 hours once or twice a week. These sample collections are scaled up to monthly totals in the following way (Exhibit UT-6, p. 10.2-6):

Impingement samples were used to estimate the total number of selected species impinged monthly and annually at Roseton. Each month was divided into four time intervals: day 1 to 7, day 8 to 14, day 15 to 21, day 22 to last day of the month. For each time interval the total number of fish collected was divided by the total flow in million gallons for all samples within that interval, to produce an impingement rate. The impingement rate (number of fish per million gallons) for the four time intervals was averaged to produce a mean monthly impingement rate. When there was no sample taken within one of the four time intervals, the remaining intervals were averaged to obtain the monthly rate. The mean monthly impingement rate was then multiplied by the total monthly plant flow in million gallons to produce an estimated total number of fish impinged per month. The monthly totals were summed to obtain an annual total.

An equivalent paragraph can be found on p. 10.2-6 of Exhibit UT-7. Similar methods have been used at Lovett (Lawler, Matusky, and Skelly 1976a), Danskammer (Lawler, Matusky, and Skelly 1974), and Albany (Lawler, Matusky, and Skelly 1975). This method of scaling up impingement samples is critically dependent on the assumption that the number of fish impinged during any period is directly proportional to the total intake flow during that period. The utilities' consultants and I agree that in reality this is not always the case (Transcript pp. 4333-37). Texas Instruments (1974), for example, did not find a strong correlation between impingement counts and volumetric flow rates at Indian Point Units 1 and 2. Although the failure of this assumption necessarily reduces the precision of the resulting impingement estimates, I do not believe that it introduces a bias toward either underestimating or overestimating the number of fish impinged per month.

## 1.2 BIASES THAT INFLUENCE IMPINGEMENT ESTIMATES

Although the questionable assumption that impingement is proportional to power plant intake flow probably does not introduce biases into the monthly and annual impingement estimates, four phenomena that do introduce such biases have been identified. The utilities have assumed (Exhibit UT-3, Sections 2-VI and 2-VII) that, with the exception of Indian Point Units 2 and 3, these biases offset one another and no adjustments of the impingement estimates are necessary. I believe that for some species at some plants the biases clearly do not offset one another, and therefore, some adjustments are necessary.

### 1.2.1 Collection Efficiency

Not all impinged fish are actually collected and counted during screenwash monitoring, for reasons that are not completely understood. Some fish are probably washed back into the river by tidal action. Some may slip through gaps between screens or may not be removed from the screens by the

screenwash spray. Others are probably scavenged from the screens by gulls, crabs, and eels. Utility consultants have conducted studies at Indian Point, Bowline, and Roseton in order to estimate the fraction of impinged fish that are actually collected and counted. In Exhibit UT-7 (Table 10.2-4) the utilities estimate collection efficiency at Bowline to be about 90%. Recent data collected by LMS have convinced me that in reality collection efficiency at Bowline is considerably lower, less than 80%. No collection efficiency studies at Roseton were reported in Exhibit UT-6, but studies performed after this exhibit was filed indicate that collection efficiency at this plant averages no higher than 75% and is lower for the small fish (< 13 cm in length) that dominate impingement collections.

For purposes of impact assessment the utilities have assumed (Exhibit UT-3, Sections 2-VI and 2-VII) that collection efficiency at Indian Point Unit 3 is 80%. Although this figure is consistent with preliminary collection efficiency studies performed by Texas Instruments (1977a), more recent studies (Section 2) indicate a somewhat lower value (approximately 70%). Collection efficiency at Indian Point Unit 2 is extremely low. The utilities have used a value of 15% in their impact assessments (Exhibit UT-3, Sections 2-VI and 2-VII); more recent studies confirm the accuracy of this value.

#### 1.2.2 Reimpingement

On days when impinged fish are not sampled, impinged fish are returned to the river. If the point of return is relatively close to the intake structure, some of these fish may be drawn back into the intake and reimpinged. On days when impinged fish are sampled, the fish collected will include all fish impinged for the first time on that day (subject to adjustments for collection efficiency), and also some fish that have been impinged one or more times previously.

Ideally, the impingement count over 24 hours should include only (but all) those fish impinged for the first time. Such a count is an estimate of the total number impinged one or more times (if they had not been collected, a fraction of them would have been subsequently reimpinged). Including reimpinged fish in effect double-counts reimpinged fish and inflates estimates of the total number of fish that are impinged.

Studies conducted at Bowline by Ecological Analysts (Exhibit UT-7, Sections 10.3.2.2 and 10.3.3.2) indicate that with the sampling methods now employed at Bowline, approximately 10% of the fish collected have been previously impinged. On the basis of studies at Roseton and Danskammer (Exhibit UT-6), I believe that reimpingement is negligible at all other plants.

### 1.2.3 Impingement on Inoperative Screens

At Bowline and Roseton the two generating units share a common intake bay containing all circulator pumps and travelling screens. Thus, when a screen is inoperative and cannot be rotated and washed, it continues to impinge fish. By my calculations (based on results reported in Section 10.2.3.1.4 of Exhibit UT-7), a screen that is inoperative for 1 to 5 days impinges about 11% as many fish as does a normally operating screen during the same period. According to Exhibit UT-7 (p. 10.2-12), such breakdowns occurred "on many occasions from 1974 through 1976" at Bowline.

### 1.2.4 Impingement Survival

Results reported in Exhibits UT-6 and UT-7 indicate that not all impinged fish are killed as a direct result of the impingement experience. Although the magnitude of indirect impingement mortality (e.g., increased susceptibility to disease or vulnerability to predators due to the stress of impingement) has not been estimated, it appears that under certain operating conditions the survival of several species (most notably Atlantic tomcod) can be substantial. Assuming that all impinged fish are killed will, in the absence of offsetting biases, tend to inflate estimates of impingement impact.

## 2. EVALUATION OF UTILITY ESTIMATES OF THE NUMBER OF FISH IMPINGED

I believe that the utilities have underestimated the monthly and annual numbers of white perch, striped bass, and clupeids killed by impingement at Hudson River power plants. My two specific points of disagreement are:

- (1) The utilities do not include fish impinged at Danskammer, Lovett, or Albany.
- (2) Utility estimates of collection efficiency at Indian Point Unit 3, Bowline, and Roseton are too high.

Fish killed at Lovett, Danskammer, or Albany are just as dead as those killed at Indian Point, Bowline, or Roseton. The impact of impingement at the three plants at issue in these proceedings is an incremental impact added to the preexisting impacts caused by impingement at Lovett, Danskammer, and Albany. Neither the significance to Hudson River fish populations of the additional losses caused by impingement at Indian Point, Bowline, and Roseton, nor the reduction in impact that would result from the installation of mitigating measures (e.g., closed-cycle cooling), can be understood unless the impacts of all six plants are considered.

With reference to the second point of disagreement, whether the impingement estimates calculated by the utilities must be scaled up to account for lower estimates of collection efficiency depends upon the magnitude of any offsetting biases. Of the three sources of bias (in addition to collection efficiency) described in Section 1.2, impingement survival is undoubtedly the most important. My analysis of the utilities' impingement survival studies indicates that the survival of impinged white perch and striped bass at Bowline, Roseton, Danskammer, and Albany is probably high enough to offset the bias due to collection efficiency. Atlantic tomcod survival during the fall, winter, and early spring at these plants appears to be high enough so that impingement estimates for this species, for these seasons, should be scaled down. Survival of clupeids at all plants, and survival of all species at Indian Point (where no fish are returned to the river) and Lovett appears to be negligible.

The remainder of this section consists of my assessments of the magnitude of each of the four biases discussed in Section 1.2 and how they vary among plants and fish species.

### 2.1 COLLECTION EFFICIENCY

#### 2.1.1 Indian Point Unit 2

The results of all collection efficiency tests carried out to date at Indian Point Unit 2 are summarized in Exhibit UT-105. Tests were first performed at this unit in 1974 and 1975. The results of these tests

indicated that with the air curtain operating, only about 15% of the impinged fish were being collected and counted (Texas Instruments 1975, 1976). It appeared from preliminary tests in 1974 and 1975 that collection efficiency increased to about 50% when the air curtain was turned off (Texas Instruments 1976). In 1977, after air curtain operation was permanently discontinued, new tests were conducted. Surprisingly, the 1977 results were no different from those obtained earlier with the air curtain operating. Of 1500 test fish released in May and June of 1977, only 224 (14.9%) were recovered (Exhibit EPA-94). No explanation has been offered as to why the 1977 results differ so greatly from those obtained in the earlier tests with the air curtain off.

The 1977 experiments involved more release dates (9 vs 3) and more fish (1500 vs 1000) than did those performed in 1974-75. Until the cause of the discrepancy is discovered, I believe that the results of the more extensive 1977 experiments should form the basis for an estimate of collection efficiency at Indian Point Unit 2. These results support the value (15%) used by the utilities in Exhibit UT-3.

#### 2.1.2 Indian Point Unit 3

The estimate of collection efficiency at Indian Point Unit 3 used in the utilities' calculations of conditional impingement mortality rates (Exhibit UT-3, Sections 2-VI and 2-VII; Exhibit UT-6, Section 10.4; Exhibit UT-7, Section 10.4) is based on the results of tests conducted in 1976 (Exhibit UT-105, Table 1, part e). Seven separate experimental releases of marked fish were conducted during June, July, and August of 1976. The percent recovery of the released fish ranged from 75% to 86%, with a mean of 79.9%. More extensive tests were conducted during 1977 (Exhibit UT-105, Table 1, part e). These new tests involved 32 separate experimental releases carried out on 11 days between March and September. The percent recoveries observed during the 1977 tests were more variable and, on the average, substantially lower than those observed in 1976. Overall, 68.9% (1323 out of 1919) of the fish released in 1977 were recovered. Pooling all the data from both years yields a percent recovery of 71.2% (1758 out of 2469). I believe that a collection efficiency of 70% is an appropriate adjustment factor for the impingement estimates at Indian Point Unit 3.

#### 2.1.3 Bowline

Results of experiments designed to measure collection efficiency at Bowline are presented in Table 10.2-4 of Exhibit UT-7. The data reported in this table were derived from eight experimental releases conducted during the period January 31-March 21, 1977. The percent recaptures from these releases were all very high, ranging from 81% to 98%, with a mean of 89%. However, this prefiled testimony reflects incomplete data. More complete data covering the period October 1976-May, 1978 indicates that collection

efficiency at Bowline is probably less than 80%. Exhibit EPA-96 contains the results obtained from 30 releases conducted by LMS between October 27, 1976 and June 29, 1977. Exhibits UT-113, UT-114, and UT-115 contain the results of 88 experiments spanning the period October 26, 1976-May 29, 1978. These results include all of the results contained in Exhibits UT-7 and EPA-96.

LMS did not use the 1976-78 data to calculate an overall estimate of collection efficiency at Bowline. Instead, Exhibit UT-115 contains two separate estimates of collection efficiency for each month, calculated in two different ways. The first estimate for each month was obtained by computing the percent recoveries for each experimental release during that month, and then averaging these percent recoveries. Results obtained from releases involving fewer than 50 fish, as well as results obtained from the purportedly aberrant release of May 2, 1977, were deleted from these estimates. The second estimate for each month was obtained by pooling the data collected during that month. That is, the percent recovery was computed by dividing the total number of fish recovered from all experimental releases during that month by the total number of fish released.

I prefer the second method of computation. I have no quarrel with the exclusion of data on the grounds of insufficient sample size. However, I am not convinced that it is legitimate to exclude data simply because the sampling conditions were unusual. The particular experimental release at issue here is that conducted on May 2, 1977. In Exhibit EPA-96 (p. 1) LMS stated:

The malfunction of the screenwash pumps combined with heavy debris provided for a non-quantitative estimate of recovery efficiency.

On transcript pp. 4426-27 Mr. Dew of LMS elaborated. He explained that the travelling screen onto which the fish had been released on May 2 could not be completely cleaned because of unusually low screenwash pressure combined with high debris load. Many fish apparently became entangled in debris that could not be washed off the screen. Consequently, only 2 of 100 released fish were recovered.

It seems likely that "unusual" conditions, such as those described by Mr. Dew, must occur occasionally on days when impingement collections are made. In fact, May 2, 1977 was an impingement collection date, according to Mr. Dew (transcript p. 4426). Although the collection efficiency data for May 2 were deleted by LMS, the impingement collection itself was considered valid and was used to estimate impingement rates for the Bowline plant (testimony of Mr. Dew, transcript p. 4426). I believe that collection efficiency studies should be conducted under the same range of conditions that prevail during ordinary impingement collections. Collection efficiency data generated under abnormal conditions should not be discarded unless impingement collections made under the same conditions are also discarded. I have calculated a collection efficiency for Bowline by summing the releases and recaptures for all of the experiments, including that of May 2, 1977.

This computational method allows data from all the experiments to be used, not just from those in which 50 or more fish were released. With this method the results obtained from each experiment are, in effect, weighted by the number of fish released. The results of my computations are presented in Table 1. The calculated collection efficiency is 75.7%. If the May 2, 1977 results are excluded, this value increases only slightly, to 76.8%. I conclude on the basis of the LMS studies that collection efficiency at Bowline is between 75% and 80%, or more than 10% lower than is reported in Exhibit UT-7.

#### 2.1.4 Roseton

Although no collection efficiency studies are reported in Exhibit UT-6, such studies were conducted at Roseton in 1978. Results covering the period January-March are contained in Exhibit EPA-97. Of 606 marked fish released on 12 separate release dates, 458 were recaptured, yielding a recovery percentage of 75.6%. Interestingly, Exhibit EPA-97 contains a breakdown of the release/recovery data by size-class. Table 2 of Exhibit EPA-97 shows that collection efficiency is strongly affected by the size of impinged fish. It is particularly noteworthy that the collection efficiency for fish less than 13 cm. in length was only 53.5%. The vast majority of impinged white perch, striped bass, Atlantic tomcod, alewife, blueback herring, American shad, and bay anchovy are less than 13 cm long. Thus, collection efficiency for the species of interest in these proceedings may be well below 75%. If fish larger than 25 cm length are removed from the computations (very few impinged fish belonging to the species of interest are that large), the percent recovery of the remaining fish is 71.6%. I conclude on the basis of the data in Exhibit EPA-97 that collection efficiency at Roseton, for fish of species and size that are of principal interest to these proceedings, is probably no higher than 70%, and may be considerably lower.

## 2.2 REIMPINGEMENT

### 2.2.1 Indian Point Units 2 and 3

Reimpingement is not a source of bias at Indian Point because impinged fish are not returned to the river.

### 2.2.2 Bowline

Section 10.3.3.2 of Exhibit UT-7 contains results of some rather elegant experiments conducted by Ecological Analysts (EA) in order to estimate the reimpingement rate at Bowline. Of particular interest are the results of the "long-term survey" (Section 10.3.3.2.2), as these results can be used to calculate the fraction of fish collected on a typical impingement sampling day that have been previously impinged. The experiment involved:

Table 1. Estimation of collection efficiency at the Bowline Point Generating Station

Dates	Number released <sup>a</sup>	Number recaptured <sup>a</sup>	% Recaptured
All release dates	6582	4981	75.7
Excluding May 2, 1977	6482	4979	76.8

<sup>a</sup>Total number of releases and recaptures from 88 experiments conducted between October 1976 and May 1978 (from Exhibit UT-114).

- (a) marking all white perch impinged during a 24-hour release period,
- (b) releasing these marked fish, and
- (c) monitoring screenwashes on subsequent days and calculating the fraction of marked fish in each day's collection of white perch.

EA released marked fish on five consecutive days, using a different color mark for each release period. The results of EA's April 1976 experiment are tabulated in Table 10.3-22 of Exhibit UT-7.

Table 10.3-22 indicates that the probability of an impinged and released fish being reimpinged is at a maximum during the first 24 hours after release and declines steadily with time to 1% or less by four days after initial impingement. EA used the data in Table 10.3-22 to derive an equation expressing the probability of reimpingement as a function of time since initial impingement:

$$P_r(t) = 20.4e^{-0.83t} , \quad (1)$$

where  $t$  = time in days since initial impingement.

Normally, impingement sampling is conducted over one 24-hour period each week at Bowline. In order to reduce the effects of reimpingement on the impingement counts, fish impinged during the 24 hours prior to the beginning of the sampling period are not returned to Bowline Pond. Thus, fish collected during an impingement sample can include reimpinged fish that were first impinged between 1 and 6 days prior to sampling. EA used the decay rate (-0.83) from Eq. (1) and an estimate of the fraction of each day's catch composed of fish also impinged during the previous 24 hours (from Table 10.3-22) to calculate the contribution of reimpinged fish to a typical impingement sample (8.1%). I obtained a different and slightly higher (10.6%) estimate by integrating Eq. (1) from  $t=1$  to  $t=6$ .

In Table 10.3-23 of Exhibit UT-7, EA presents data obtained from a similar experiment conducted in January, 1977. Although no calculations based on these data are included in Exhibit UT-7, less reimpingement was observed during this experiment than during the April, 1976 experiment. I have used the data in Table 10.3-23 of Exhibit UT-7 to develop an equation for the January experiment similar to Eq. (1):

$$P_r(t) = 7.2e^{-0.62t} \quad (2)$$

Integrating Eq. (2) from  $t=1$  to  $t=6$  yields a value of 6.0% as the contribution of reimpinged fish to a typical impingement sample.

In my opinion, EA's experiments generally support the conclusion, stated on p. 10.2-10 of Exhibit UT-7, that approximately 10% of the fish collected during a typical impingement sample at Bowline have been previously impinged. However, the results of the January, 1977 experiment indicate that reimpingement may be a few percent lower during the winter. This observation is important because, as is shown in Tables 10.2-12 and 10.2-17 of Exhibit UT-7, impingement rates for white perch and striped bass are high at Bowline during the winter.

### 2.2.3 Roseton and Danskammer

The impingement sampling procedures employed at Roseton and Danskammer are similar to that at Bowline: the travelling screens are washed prior to the beginning of each 24-hour collection period. The fish collected during this prewash are retained rather than returned to the river. In an experiment designed to measure the reimpingement rate of white perch at Roseton (Exhibit UT-6, Section 10.3.3.2.1), it was found that virtually all reimpingement occurred within a few hours after release. The total reimpingement rate of the white perch released in this experiment was fairly high. I have calculated, using data presented in Table 10.3-9 of Exhibit UT-6, that of 914 live and dead white perch released, 163 (17.8%) were reimpinged. However, only 3 were reimpinged more than five hours after release and only one was reimpinged more than 10 hours after release. The impingement sampling procedure employed at Roseton reduces the potential for reimpingement to a very low level (Exhibit UT-6, Section 10.2.3.1.2). It is interesting that nearly all the reimpinged fish were released alive. Whereas 23.3% (158 out of 679) of the live fish were reimpinged, only 2.1% (5 out of 235) of the dead releases were recovered.

Experiments conducted at Danskammer, summarized in Section 10.2.3.1.2 of Exhibit UT-6, indicate that reimpingement at this plant is as low as that observed at Roseton. Unlike Bowline, where fish are returned to Bowline Pond, fish impinged at Roseton, Danskammer, and at all other Hudson River power plants (except Indian Point, where none are returned), are returned directly to the river. Fish (especially dead fish) returned to the river can be swept away from the vicinity of the plant by tidal flushing. Tidal flushing is undoubtedly much weaker in Bowline Pond, and may not occur at all when the plant is operating and impinging fish. I believe that this accounts for the difference observed between reimpingement at Bowline and reimpingement at Roseton and Danskammer. Reimpingement at other plants is likely to be more similar to Roseton and Danskammer (i.e., virtually no reimpingement) than to Bowline.

## 2.3 IMPINGEMENT ON INOPERATIVE TRAVELLING SCREENS

At some plants, notably at Bowline, fish can be impinged on inoperative travelling screens. Since these fish cannot be collected and counted, impingement counts for days on which one or more travelling screens are inoperative will be underestimates of the true number of fish impinged.

### 2.3.1 Indian Point Units 2 and 3

Since each travelling screen at Indian Point is located in a separate forebay, the circulator pump located in a forebay containing an inoperative screen must be shut off to prevent the clogging and eventual collapse of the screen. For this reason, impingement on inoperative screens is not a source of bias at the Indian Point Plant.

### 2.3.2 Bowline

Both generating units at Bowline draw water from a common intake bay containing six travelling screens. Section 10.2.3.1.4 of Exhibit UT-7 describes some experiments that were conducted at Bowline in order to estimate the magnitude of the bias associated with impingement on inoperative screens. The procedure is described on p. 10.2-14 of Exhibit UT-7:

From 29 November 1976 to 19 January 1977, the cleaning procedure of travelling screens at the Bowline Point intake was controlled to simulate the condition of a non-operating screen. One of the three screens at Unit 2 remained stationary for 1, 2, 3, and 5 day periods while the other two screens were cleaned every four hours. After remaining stationary for the designated number of days, the test screen was cleaned and the total number collected was compared with the total collected from all screens at Unit 2 during the test interval (Table 10.2-5).

The results of the experiment are summarized in Table 10.2-5 of Exhibit UT-7. When one of the three screens at Bowline Unit 2 was inoperative, between 5 and 7% of the total number of fish impinged at Unit 2 were not recovered. The number of days of down-time did not appear to influence the fraction of the Unit 2 total impingement that was impinged on the inoperative screen. The inoperative screen accounted for about the same fraction of the total impingement collection (7%) after five days of down-time as after only one day.

The bias estimated from Table 10.2-5 (5 to 7%) is strictly applicable only if one third of the six travelling screens at Bowline are inoperative. If only one of the six is inoperative, the bias will be smaller than that calculated in Exhibit UT-7; if more than two are inoperative, the bias will be larger. I have used the data in Table 10.2-5 to estimate the magnitude of the bias for any number of inoperative screens, up to 5. The numbers in the column headed "NUMBER COLLECTED ON NORMAL SCREENS" are the total number of fish collected from two operating screens. Dividing the values in this column by two yields an estimate of the number impinged by a single operating screen. It is possible to derive estimates of a "relative collection rate constant" (k) by calculating the ratio of the number of fish impinged on an inoperative screen to the number impinged on a normally operating screen. For example, on December 8-9, 6784 fish were collected from the two operating screens and 220 were collected from the inoperative screen. On that date

the inoperative screen impinged 6.5% [100 x (220/3392)] as many fish as did each operating screen. Therefore, our estimate of k for December 8-9 is 0.065.

I computed an overall estimate of k by summing all of the normal screen collections and test screen collections in Table 10.2-5 of Exhibit UT-7. Since results obtained from the 2-, 3-, and 5-day studies were similar to those obtained from the 1-day studies, I saw no reason to calculate k separately for each data set. My overall estimate of k, calculated by the same procedure used in the above example, is 0.117.

If one or more screens are inoperative, the number of fish impinged on these screens is equal to the number impinged per operating screen multiplied by k times the number of inoperative screens:

$$I_i = (I_0/n_0)kn_i \quad , \quad (3)$$

where

$I_0$  = total number of fish collected from operating screens,

$I_i$  = total number of fish impinged on inoperative screens,

$n_0$  = number of operating screens,

$n_i$  = number of inoperative screens,

k = relative collection rate constant.

The total number of fish impinged on all screens can be calculated from the following equation:

$$\begin{aligned} I_T &= I_0 + I_i \\ &= I_0 + (I_0/n_0)kn_i \\ &= I_0 (1 + kn_i/n_0) \quad , \end{aligned} \quad (4)$$

where

$I_T$  = estimated total impingement on all screens.

The term in parentheses  $(1 + kn_i/n_0)$  is an adjustment factor similar to the factors calculated for collection efficiency. Table 2 contains my inoperative screen adjustment factors, calculated for 1-5 inoperative screens.

Table 2. Inoperative screen adjustment factors, calculated for 1 to 5 inoperative screens out of a total of 5.

	Number of inoperative screens				
	1	2	3	4	5
Adjustment factor (= $1 + kn_j/n_0$ ) <sup>a</sup>	1.023	1.059	1.117	1.234	1.585

<sup>a</sup> $n_j$  = number of inoperative screens

$n_0$  = number of operating screens

k = relative impingement rate constant (calculated from Table 10.2-5 of Exhibit UT-7) = 0.117.

It can be seen from Table 2 that unless more than two screens are inoperative, the bias in impingement estimates will be 6% or less for each day of down-time. Unless multiple screens are inoperative for extended period of time (i.e., weeks or months), biases due to the impingement of fish on inoperative screens will be negligible in comparison to the effects of reimpingement or collection efficiency at Bowline. Moreover, it seems likely that during an extended outage, an inoperative screen would eventually clog completely with debris and cease impinging fish altogether. I tentatively conclude that impingement on inoperative screens is a relatively unimportant source of bias in the Bowline impingement estimates.

It is possible that I have underestimated the magnitude of this bias, for the following reason. Substantial numbers of fish may be scavenged from an inoperative screen by crabs and eels, especially if the screen is not cleaned for several days. This scavenging would result in the collection efficiency of an inoperative screen being lower than that of an operating screen (frequent washing reduces the opportunity for scavenging). This difference in collection efficiencies would, in turn, bias the results of the experiments described in this section by causing the contribution of the inoperative screen to the total impingement count to be underestimated.

### 2.3.3 Roseton

Like Bowline, the two units at Roseton share a common intake bay, and thus it is possible for fish to be impinged on inoperative screens. The longest screen outage at Roseton during 1974 was 48 hours (Huggins 1977). Outages longer than two weeks in duration occurred three times in 1975 and four times in 1976. Three screens (out of eight) were out of service between October 13 and November 11, 1976. All of the other extended outages involved single screens. With the possible exception of the October-November 1976 outage, I believe that impingement on inoperative screens has had a negligible effect on the accuracy of Central Hudson's estimates of impingement at Roseton.

## 2.4 IMPINGEMENT SURVIVAL

In their impact assessments the utilities have assumed that all impinged fish are killed. If this is in fact the case, then the impingement estimates presented by the utilities for Bowline and Roseton (and also those for Lovett, Danskammer, and Albany) must be scaled up to account for biases due to collection efficiency. However, if survival is substantial, then no adjustment of these estimates may be necessary. If survival is very high, the impingement estimates may have to be scaled down.

Impingement survival studies have been conducted at Bowline, Roseton, Danskammer, and Indian Point Unit 3. As fish impinged at Indian Point were not returned to the river during any of the years for which impingement data are available, the studies there are not relevant to estimating the impact

of impingement during those years and are not discussed here. Studies conducted at the other three plants have indicated that under some operating conditions survival of some species may be fairly high. Experiments at all three plants have shown that impingement survival is highest when travelling screens are rotated and washed continuously. However, under current operating procedures travelling screens at all plants are operated intermittently rather than continuously (operation at Albany is almost continuous). In fact, it is apparently not possible to operate the travelling screens continuously for extended periods of time. On transcript pp. 4465-68 Mr. Hutchison describes the serious problems encountered at Bowline because of extended operation in the continuous mode. Because the travelling screens at Bowline were not designed for continuous rotation, breakdowns have been frequent. Each of the six screens has been rebuilt twice. Current practice, according to Mr. Hutchison (transcript pp. 5099-100), is to rotate the screens continuously only when impingement exceeds 1000 fish per day. Table 3 summarizes the current screenwash procedures at Bowline, Lovett, Roseton, Danskammer, and Albany.

In the following sections I discuss the design of the impingement survival experiments conducted at Bowline, Roseton, and Danskammer and the results obtained for Atlantic tomcod, clupeids, white perch, and striped bass.

#### 2.4.1 Experimental Methods

Sections 10.3.2 of Exhibits UT-6 and UT-7 contain descriptions of the methods used in impingement survival studies conducted by Ecological Analysts (EA) at Roseton and at Bowline. Although no description of the methods used at Danskammer is included in Exhibit UT-6, EA's 1977 Progress Report to Central Hudson (Ecological Analysts 1977) indicates that they are virtually identical to the procedures at Roseton.

In most of the studies at Bowline impinged fish are collected in a nylon mesh bag suspended in the impingement collection pit. In some of the experiments at Bowline, fish have been collected at the end of the screenwash discharge pipe in an effort to assess whether the screenwash discharge system imposes stresses in addition to those caused by the impingement experience itself. At Roseton and Danskammer fish are collected in a basket that floats in the river at the end of the discharge pipe.

After collection the fish are sorted immediately by species and are classified as live, dead, or stunned. The live and stunned fish are then transferred to a holding facility and observed for latent mortality. The holding period at Bowline is 96 hours; at Roseton and Danskammer it is 84 hours. The use of control fish has been an important element in all the impingement survival studies. In the first such studies (conducted at Roseton and Danskammer in 1975), control fish were exposed only to the holding facilities. Subsequently, control fish have been exposed to the entire process of collection, holding, and observation.

Table 3. Normal operating procedures for travelling screens operating at five Hudson River power plants

Plant	Mode	Screenwash pressure (psi)	Source of information
Bowline	Intermittent; 4-hour hold <sup>a</sup>	30/60 <sup>b</sup>	Exhibit 7, pp. 2.2-10, 2.2-11; transcript pp. 5099-100
Lovett	Intermittent; 8-hour hold <sup>c</sup>	100	Attachment 2 to letter from K. Marcellus of Consolidated Edison to H. Gluckstern of EPA, dated November 30, 1977; Transcript p. 5098
Roseton	Intermittent; 2-hour hold <sup>d</sup>	100	Letter from T. Huggins of Central Hudson to H. Gluckstern of EPA, dated November 29, 1977; Transcript p. 5098
Danskammer	Intermittent; variable depending on debris load	55-65	Letter from T. Huggins of Central Hudson to H. Gluckstern of EPA, dated November 29, 1977; EA 1977 Progress Report to Central Hudson, Table 4-26
Albany	Screens washed automatically for 3 minutes every 15 minutes	84	Attachment 2 to letter from K. Marcellus of Consolidated Edison to H. Gluckstern of EPA, dated November 30, 1977

<sup>a</sup>Operated in continuous mode when impingement exceeds 1000 fish per day.

<sup>b</sup>Low pressure (30 psi) wash system mounted below high pressure (60 psi) system.

<sup>c</sup>Operated in continuous mode during periods of high debris loading.

<sup>d</sup>Operated in continuous mode during periods of high debris loading and icing (such conditions generally occur between October and April).

#### 2.4.2 Results of the Impingement Survival Studies

The results of the impingement survival experiments conducted at Bowline by LMS in 1974 and 1975 and by EA in 1976 and 1977 are described in Section 10.3.3.1 of Exhibit UT-7. Section 10.3.3.1 of Exhibit UT-6 contains results of similar experiments conducted by EA at Roseton in 1975-76. Additional results from EA's 1977 studies at Roseton, as well as results obtained by EA at Danskammer during 1975-77, are described in EA's 1977 Progress Report to Central Hudson (Ecological Analysts 1977). Many of these results are inconclusive and/or inconsistent. However, two general conclusions emerge:

- (1) Survival is highly variable among species. Survival of adult Atlantic tomcod is uniformly high during the fall and winter, and that of clupeids (primarily Alosa spp.) is uniformly low during all seasons. Survival of white perch and striped bass is intermediate.
- (2) Survival of white perch and striped bass is related to screenwash procedures. Highest survival is observed when screens are rotated and washed continuously. Lowest survival occurs when operation is intermittent.

##### 2.4.2.1 Atlantic tomcod

Results of the Atlantic tomcod survival studies at Bowline, Roseton, and Danskammer are summarized in Table 4. With the exception of 45 juvenile tomcod collected at Bowline in 1974 by LMS (discussed below), all tomcod survival studies have involved adult fish impinged during the fall, winter, or early spring. Survival of these fish has been high under virtually all operating conditions at all three plants. Low survival was reported in several experiments at Roseton and Danskammer involving a four-hour screenwash cycle. Few fish (at most 6) were tested in these experiments, and thus, the reliability of the results is low. High survival was observed at Bowline under the same conditions. Survival percentages of adult tomcod appear to be consistently higher at Bowline than at Roseton. This result may be partially due to differences in screenwash pressure (Table 3). At Bowline the highest pressure used in any of the experiments is 60 psi. In contrast, high pressure at Roseton means 100 psi, the normal operating pressure at that plant. Low pressures used at Bowline range from 10 to 30 psi, while at Roseton the lowest pressure used is 50 psi.

Survival of impinged juvenile Atlantic tomcod may be less than that of adults. These cold-adapted fish (Exhibit EPA-198) are impinged primarily during the summer (transcript p. 10,803), when they may already be stressed because of high water temperatures (Texas Instruments 1977b, p. V-75). The additional stress of impingement may be sufficient to cause substantial mortality. The meager evidence available to date supports this hypothesis. Of the 45 impinged juveniles collected by LMS in June, 1974, only 43% survived for 96 hours in the holding facility. Unfortunately, no control fish were collected, and therefore, it is not possible to say with certainty

Table 4. Summary of Atlantic tomcod impingement survival data

Period	Collection point	Operating mode and screenwash pressure	Number of fish tested	% Survival <sup>a</sup>	Source
BOWLINE					
November-December 1976	Collection pit	Continuous, high pressure	3	100	Exhibit 7 Table 10.3-4
		Continuous, low pressure	46 <sup>b</sup>	100	
		Intermittent, high pressure	6 <sup>b</sup>	100	
		Intermittent, low pressure	3 <sup>b</sup>	100	
December 1976	Discharge pipe	Continuous, high pressure	1	100	Exhibit 7 Table 10.3-6
		Continuous, low pressure	1	100	
		Intermittent, high pressure	2	100	
		Intermittent, low pressure	3	100	
June 1974	Collection pit	Unknown	45	43	Exhibit UT-7 Table 10.3-14
ROSETON					
January-March 1976	Collection basket	Continuous, high pressure	92 <sup>b</sup>	85	Exhibit UT-6 Table 10.3-1
		Intermittent, 2-hr hold, high pressure	43	77	

Table 4. (continued)

Period	Collection point	Operating mode and screenwash pressure	Number of fish tested	% Survival <sup>a</sup>	Source
ROSETON					
Fall 1975	Collection basket	Continuous, high pressure	4	0	Exhibit UT-6 Table 10.3-3
		Intermittent, 2-hr hold, high pressure	13	8	
		Intermittent, 4-hr hold, high pressure	2	0	
November-December 1976	Collection basket	Continuous, low pressure	19	84	Exhibit UT-6 Table 10.3-5
		Continuous high pressure	67	97	
		Intermittent, 2-hr hold, low pressure	13	69	
		Intermittent, 2-hr hold, high pressure	20	90	
		Intermittent, 4-hr hold, low pressure	2	100	
		Intermittent, 4-hr hold, high pressure	1	0	
January-March 1977	Collection basket	Continuous, low pressure	108	83	EA 1977 <sup>c</sup> Table 4-13
		Continuous, high pressure	120	63	

Table 4. (continued)

Period	Collection point	Operating mode and screenwash pressure	Number of fish tested	% Survival <sup>a</sup>	Source
ROSETON					
January-March 1977	Collection basket	Intermittent, 2-hr hold, low pressure	73	66	EA 1977 <sup>c</sup> Table 4-13
		Intermittent, 2-hr hold, high pressure	111	70	
DANSKAMMER					
Fall 1975	Collection basket	Intermittent, <sup>d</sup> 4-hr hold	6	0	EA 1977 Table 4-25
November-December 1976	Collection basket	Continuous	36	75	EA 1977 Table 4-27
		Intermittent, 2-hr hold	29	72	
January-March 1977	Collection basket	Continuous	242	83	EA 1977 Table 4-31
		Intermittent, 2-hr hold	716	87	
<u>SURVIVAL OF CONTROLS EXPOSED ONLY TO COLLECTION AND HOLDING PROCEDURE</u>					
BOWLINE					
November-December 1976	Collection pit		3	100	Exhibit UT-7 Table 10.3-5

Table 4. (continued)

Period	Collection point	Operating mode and screenwash pressure	Number of fish tested	% Survival <sup>a</sup>	Source
ROSETON					
November-December 1976	Collection basket		20	100	Exhibit UT-6 Table 10.3-6
January-March 1977			208	98	EA 1977 page 4-25

<sup>a</sup>Percent alive at end of observation period (96 hours at Bowline, 84 hours at Roseton and Danskammer).

<sup>b</sup>Data collected under the same conditions (sampling point, operating mode, and screenwash pressure) are pooled.

<sup>c</sup>Ecological Analysts 1977 Progress Report to Central Hudson.

<sup>d</sup>Screenwash pressure for all impingement survival studies at Danskammer is 55-65 psi.

whether it was the stress of impingement or the stress of collection and observation that was responsible for the mortality.

#### 2.4.2.2 Clupeids

There have been relatively few studies relating to the survival of impinged clupeids (alewife, blueback herring, American shad, and gizzard shad). What data do exist show that these fish are extremely sensitive to stress. As can be seen from Table 5, virtually none of the impinged clupeids collected and held for observation at Bowline, Roseton, and Danskammer have survived to the end of the holding period. I do not believe that more than negligible survival of these fish occurs at any plant under current modes of travelling screen operation.

#### 2.4.2.3 White Perch and Striped Bass

Results of latent survival studies involving white perch (Table 6) and striped bass (Table 7) have shown that these species are intermediate between the more hardy Atlantic tomcod and the highly sensitive clupeids with respect to their resistance to the stress of impingement. Because of the high variability of these results, it is not possible to estimate the fractional survival of impinged white perch and striped bass with the same accuracy and precision possible for estimates of collection efficiency or impingement. It is, however, possible to make qualitative assessments of seasonal variations in survival and of the effects of screenwash procedures on survival.

My assessments of these effects will apply to both species, even though in many cases the only available data relate to white perch. A priori, one would expect the responses to stress of these two closely related species to be similar. Experiments conducted at Bowline between 1974 and 1976, the only series of experiments that involved substantial numbers of striped bass, support this intuitive judgment. I have used the data in Tables 6 and 7 to compare the percent survivals of impinged white perch and striped bass collected at Bowline under the same conditions (Table 8). The correlation between the two sets of numbers ( $r = 0.64$ ) is statistically significant at the 1% level. Moreover, neither species exhibited consistently higher survival over all experimental conditions; observed white perch survival was higher than that of striped bass in five of the fifteen comparisons, and was lower in seven.

Even a superficial inspection of Table 8 shows that for both white perch and striped bass, survival is considerably higher when the travelling screens at Bowline are operated in the continuous mode than when the intermittent mode is employed. However, Table 6 shows that this pattern has not been consistently observed for white perch impinged at Roseton and Danskammer. The highest survival of white perch at both of these plants has been obtained during continuous operation: eight out of nine observations of 40% latent

Table 5. Summary of clupeid impingement survival data

Period	Collection point	Operating mode and screenwash pressure	Number of fish tested	% Survival <sup>a</sup>	Source
BOWLINE					
November-December 1976	Collection pit	Continuous, high pressure	89 <sup>b</sup>	10	Exhibit UT-7 Table 10.3-4
		Continuous, low pressure	51	0	
		Intermittent, high pressure	28	0	
		Intermittent, low pressure	22	0	
November-December 1976	Discharge pipe	Continuous, high pressure	1	0	Exhibit UT-7 Table 10.3-6
		Continuous, low pressure	9	0	
		Intermittent, high pressure	1	0	
		Intermittent, low pressure	2 <sup>b</sup>	0	
November 1974	Collection pit	Unknown	60	0	Exhibit UT-7 Table 10.3-14
	Discharge pipe	Unknown	93	0	
ROSETON					
Fall 1975	Collection basket	Continuous, high pressure	24 <sup>c</sup>	0	Exhibit UT-6 Table 10.3-3
		Intermittent, 2-hr hold, high pressure	5995 <sup>c</sup>	0	

Table 5. (continued)

Period	Collection point	Operating mode and screenwash pressure	Number of fish tested	% Survival <sup>a</sup>	Source
ROSETON					
Fall 1975	Collection basket	Intermittent, 4-hr hold, high pressure	381 <sup>c</sup>	0	Exhibit UT-6 Table 10.3-3
		Intermittent, 6-hr hold, high pressure	4645 <sup>c</sup>	0	
DANSKAMMER					
Fall 1975	Collection basket	Continuous <sup>d</sup>	107 <sup>c</sup>	1	EA 1977 <sup>e</sup> Table 4-25
		Intermittent, 2-hr hold	162 <sup>c</sup>	0	
		Intermittent, 4-hr hold	314 <sup>c</sup>	0	
		Intermittent, 6-hr hold	2436 <sup>c</sup>	0	
<u>SURVIVAL OF CONTROL FISH EXPOSED ONLY TO COLLECTION AND HOLDING PROCEDURE</u>					
BOWLINE					
November 1976	Collection pit		40	0	Exhibit UT-7 Table 10.3-5

<sup>a</sup>Percent alive at end of observation period (96 hours at Bowline, 84 hours at Roseton and Danskammer).

<sup>b</sup>Data collected under the same conditions (sampling point, operating mode, and screenwash pressure) are pooled.

<sup>c</sup>Data for all clupeid species are pooled.

<sup>d</sup>Screenwash pressure for all impingement survival studies at Danskammer is 55-65 psi.

<sup>e</sup>Ecological Analysts 1977 Progress Report to Central Hudson.

Table 6. Summary of white perch impingement survival data

Period	Collection point	Operating mode and screenwash pressure	Number of fish tested <sup>a</sup>	% Survival <sup>b</sup>	Source	
BOWLINE						
January-December 1976	Collection pit	Continuous, high pressure	2483 <sup>c</sup>	61	Exhibit UT-7 Table 10.3-4	
		Continuous, low pressure	3701 <sup>c</sup>	49		
		Intermittent, high pressure	1339 <sup>c</sup>	26		
		Intermittent, low pressure	1281 <sup>c</sup>	23		
	Discharge pipe	Continuous, high pressure	390 <sup>c</sup>	20	Exhibit UT-7 Table 10.3-6	
		Continuous, low pressure	274 <sup>c</sup>	17		
		Intermittent, high pressure	609 <sup>c</sup>	10		
Intermittent, low pressure			966 <sup>c</sup>	9		
	January-February 1977	Collection pit	Continuous, high pressure	958 <sup>c</sup>	28	Exhibit UT-7 Table 10.3-9
			Continuous, low pressure	988 <sup>c</sup>	21	
	Discharge pipe	Continuous, high pressure	25	29		
Continuous, low pressure		28	0			

Table 6. (continued)

Period	Collection point	Operating mode and screenwash pressure	Number of fish tested <sup>a</sup>	% Survival <sup>b</sup>	Source
BOWLINE					
November-December 1974	Collection pit	Continuous, high pressure	837 <sup>c</sup>	26	Exhibit UT-7 Table 10.3-10
January 1975	Collection pit	Continuous, high pressure	678 <sup>c</sup>	7	Exhibit UT-7 Table 10.3-10
April 1975	Collection pit	Continuous, high pressure	55 <sup>c</sup>	35	Exhibit UT-7 Table 10.3-10
November-December 1974	Discharge pipe	Continuous, high pressure	807 <sup>c</sup>	23	Exhibit UT-7 Table 10.3-11
March-April 1975	Discharge pipe	Continuous, high pressure	543 <sup>c</sup>	7	Exhibit UT-7 Table 10.3-11
March 1975	Discharge pipe	Intermittent, 2-hr hold, high pressure	51	5	Exhibit UT-7 Table 10.3-11
March-April 1975	Discharge pipe	Intermittent, 4-hr hold, high pressure	848 <sup>c</sup>	0	Exhibit UT-7 Table 10.3-11
ROSETON					
Fall 1975	Collection basket	Continuous, high pressure	201	8	Exhibit UT-6 Table 10.3-3
		Intermittent, 2-hr hold, high pressure	667	1	
		Intermittent, 4-hr hold, high pressure	239	0	

Table 6. (continued)

Period	Collection point	Operating mode and screenwash pressure	Number of fish tested <sup>a</sup>	% Survival <sup>b</sup>	Source
ROSETON					
		Intermittent, 6-hr hold, high pressure	684	0	
April-June 1976	Collection basket	Continuous, high pressure	275 (yearling and adult)	16	Exhibit UT-6 Table 10.3-2
April-June 1976	Collection basket	Intermittent, 2-hr hold, high pressure	96 (yearling and adult)	9	Exhibit UT-6 Table 10.3-2
		Intermittent, 4-hr hold, high pressure	66 (yearling and adult)	0	
November-December 1976	Collection basket	Continuous, low pressure	285	44	Exhibit UT-6 Table 10.3-4
		Continuous, high pressure	707	4	
		Intermittent, 2-hr hold, low pressure	389	8	
		Intermittent, 2-hr hold, high pressure	344	5	
		Intermittent, 4-hr hold, low pressure	25	16	
		Intermittent, 4-hr hold, high pressure	70	0	

Table 6. (continued)

Period	Collection point	Operating mode and screenwash pressure	Number of fish tested <sup>a</sup>	% Survival <sup>b</sup>	Source
ROSETON					
		Continuous, low pressure	10 (yearling)	40	
		Continuous, high pressure	9 (yearling)	0	
		Intermittent, 2-hr hold, low pressure	22 (yearling)	14	
November-December 1976	Collection basket	Intermittent, 2-hr hold, high pressure	9 (yearling)	11	Exhibit UT-6 Table 10.3-4
		Intermittent, 2-hr hold, low pressure	7 (adult)	14	
		Intermittent, 2-hr hold, high pressure	4 (adult)	25	
January-March 1977	Collection basket	Continuous, low pressure	15	0	EA 1977 <sup>d</sup> Table 4-14
		Continuous, high pressure	49	0	
		Intermittent, 2-hr hold, low pressure	16	0	
		Intermittent, 2-hr hold, high pressure	39	0	

Table 6. (continued)

Period	Collection point	Operating mode and screenwash pressure	Number of fish tested <sup>a</sup>	% Survival <sup>b</sup>	Source
ROSETON					
April- May 1977	Collection basket	Continuous, low pressure	229	20	EA 1977 Table 4-17
		Continuous, high pressure	378	51	
		Intermittent, 2-hr hold, low pressure	74	20	
		Intermittent, 2-hr hold, high pressure	68	23	
April- May 1977 1977	Collection basket	Intermittent, 4-hr hold, low pressure	144	25	EA 1977 Table 4-17
		Intermittent, 4-hr hold, high pressure	231	10	
		Continuous, low pressure	153 (yearling)	6	
		Continuous, high pressure	171 (yearling)	2	
		Intermittent, 2-hr hold, low pressure	46 (yearling)	22	
		Intermittent, 2-hr hold, high pressure	74 (yearling)	4	
		Intermittent, 4-hr hold, high pressure	26 (yearling)	4	

Table 6. (continued)

Period	Collection point	Operating mode and screenwash pressure	Number of fish tested <sup>a</sup>	% Survival <sup>b</sup>	Source
ROSETON					
		Continuous, low pressure	89 (adult)	11	
		Continuous, high pressure	53 (adult)	8	
		Intermittent, 2-hr hold, low pressure	20 (adult)	15	
		Intermittent, 2-hr hold, high pressure	56 (adult)	11	
April-May 1977	Collection basket	Intermittent, 4-hr hold, low pressure	2 (adult)	0	EA 1977 Table 4-17
		Intermittent, 4-hr hold, high pressure	15 (adult)	18	
DANSKAMMER					
Fall 1975	Collection basket	Continuous <sup>e</sup>	268	3	EA 1977 Table 4-25
		Intermittent, 2-hr hold	236	3	
		Intermittent, 4-hr hold	924	0	
		Intermittent, 6-hr hold	137	0	

Table 6. (continued)

Period	Collection point	Operating mode and screenwash pressure	Number of fish tested <sup>a</sup>	% Survival <sup>b</sup>	Source
DANSKAMMER					
April- May 1976	Collection basket	Continuous	99 (yearling and adult)	21	EA 1977 Table 4-26
		Intermittent, 2-hr hold	71 (yearling and adult)	21	
		Intermittent, 4-hr hold	41 (yearling and adult)	0	
November- December 1976	Collection basket	Continuous	201	24	EA 1977 Table 4-27
		Intermittent, 2-hr hold	258	9	
		Continuous	17 (yearling)	53	
		Intermittent, 2-hr hold	17 (yearling)	6	
		Continuous	2 (adult)	100	
DANSKAMMER					
April- May 1977	Collection basket	Continuous	122	43	EA 1977 Table 4-34
		Intermittent, 2-hr hold	29	25	
		Intermittent, 4-hr hold	158	6	
		Continuous	248 (yearling)	33	

Table 6. (continued)

Period	Collection point	Operating mode and screenwash pressure	Number of fish tested <sup>a</sup>	% Survival <sup>b</sup>	Source
DANSKAMMER					
		Intermittent, 2-hr hold	162 (yearling)	40	
		Intermittent, 4-hr hold	62 (yearling)	0	
		Continuous	347 (adult)	45	
		Intermittent, 2-hr hold	223 (adult)	28	
		Intermittent, 4-hr hold	137 (adult)	3	
<u>SURVIVAL OF CONTROLS EXPOSED ONLY TO COLLECTION AND HOLDING PROCEDURE</u>					
BOWLINE					
November-December 1976	Collection pit		28 (yearling and adult)	86	Exhibit UT-7 Table 10.3-5
			302	32	
	Discharge pipe		134	14	Exhibit UT-7 Table 10.3-7
ROSETON					
November-December 1976	Collection basket		53	68	Exhibit UT-6 Table 10.3-6
			28 (yearling)	100	
			1 (adult)	100	

Table 6. (continued)

Period	Collection point	Operating mode and screenwash pressure	Number of fish tested <sup>a</sup>	% Survival <sup>b</sup>	Source
ROSETON					
April- May 1977	Collection basket		26	46	EA 1977 Table 4-18
			22 (yearling)	59	
			230 (adult)	89	
DANSKAMMER					
November- December 1976	Collection basket		11	91	EA 1977 Table 4-28
			5 (adult)	100	
April- May 1977	Collection basket		53	81	EA 1977 Table 4-35
			38 (yearling)	79	
			159 (adult)	84	

<sup>a</sup>Young-of-the-year unless otherwise noted.

<sup>b</sup>Percent alive at end of observation period (96 hours at Bowline, 84 hours at Roseton and Danskammer).

<sup>c</sup>Data collected under the same conditions (sampling point, operating mode, and screenwash pressure) are pooled.

<sup>d</sup>Ecological Analysts 1977 Progress Report to Central Hudson.

<sup>e</sup>Screenwash pressure for all impingement survival studies at Danskammer is 55-65 psi.

Table 7. Summary of striped bass impingement survival data

Period	Collection point	Operating mode and screenwash pressure	Number of fish tested	% Survival <sup>a</sup>	Source
BOWLINE					
January-December 1976	Collection pit	Continuous, high pressure	181 <sup>b</sup>	62	Exhibit UT-7 Table 10.3-4
		Continuous, low pressure	282 <sup>b</sup>	49	
		Intermittent, high pressure	105 <sup>b</sup>	32	
		Intermittent, low pressure	164 <sup>b</sup>	14	
November-December 1976	Discharge pipe	Continuous, high pressure	25 <sup>b</sup>	40	Exhibit UT-7 Table 10.3-6
		Continuous, low pressure	7 <sup>b</sup>	14	
		Intermittent, high pressure	65 <sup>b</sup>	24	
		Intermittent, low pressure	107 <sup>b</sup>	6	
November-December 1974	Collection pit	Continuous, high pressure	123 <sup>b</sup>	11	Exhibit UT-7 Table 10.3-12
January 1975	Collection pit	Continuous, high pressure	577 <sup>b</sup>	9	Exhibit UT-7 Table 10.3-12
April 1975	Collection pit	Continuous, high pressure	158 <sup>b</sup>	71	Exhibit UT-7 Table 10.3-12

Table 7. (continued)

Period	Collection point	Operating mode and screenwash pressure	Number of fish tested	% Survival <sup>a</sup>	Source
BOWLINE					
November-December 1974	Discharge pipe	Continuous, high pressure	86 <sup>b</sup>	19	Exhibit UT-7 Table 10.3-13
April-May 1975	Discharge pipe	Continuous, high pressure	192 <sup>b</sup>	61	Exhibit UT-7 Table 10.3-13
March 1975	Discharge pipe	Intermittent, 2-hr hold, high pressure	50	5	Exhibit UT-7 Table 10.3-13
March-April 1975	Discharge pipe	Intermittent, 4-hr hold, high pressure	98 <sup>b</sup>	0	Exhibit UT-7 Table 10.3-13
ROSETON					
Fall 1975	Collection basket	Continuous, high pressure	4	25	Exhibit UT-6 Table 10.3-3
		Intermittent, 2-hr hold, high pressure	11	0	
		Intermittent, 4-hr hold, high pressure	5	0	
		Intermittent, 6-hr hold, high pressure	6	0	
DANSKAMMER					
Fall 1975	Collection basket	Continuous <sup>c</sup>	3	0	EA 1977 <sup>d</sup> Table 4-25
		Intermittent, 2-hr hold	12	17	
		Intermittent, 4-hr hold	26	0	

Table 7. (continued)

Period	Collection point	Operating mode and screenwash pressure	Number of fish tested	% Survival <sup>a</sup>	Source
DANSKAMMER					
		Intermittent, 6-hr hold	2	0	
<u>SURVIVAL OF CONTROLS EXPOSED ONLY TO THE COLLECTION AND HOLDING PROCEDURE</u>					
BOWLINE					
November- December 1976	Collection pit		35 <sup>b</sup>	20	Exhibit UT-7 Table 10.3-5

<sup>a</sup>Percent alive at end of observation period (96 hours at Bowline, 84 hours at Roseton and Danskammer).

<sup>b</sup>Data collected under the same conditions (sampling point, operating, mode, and screenwash pressure) are pooled.

<sup>c</sup>Screenwash pressure for all impingement survival studies at Danskammer is 55-65 psi.

<sup>d</sup>Ecological Analysts 1977 Progress Report to Central Hudson.

Table 8. Comparison of observed percent survival of white perch and striped bass under identical experimental conditions, Bowline Point Generating Station (from Tables 6 and 7)

Period	Collection point	Operating mode and screenwash pressure	% Survival of white perch	% Survival of striped bass
January-December 1976	Collection pit	Continuous, high pressure	61	62
		Continuous, low pressure	49	49
		Intermittent, high pressure	26	32
		Intermittent, low pressure	23	14
	Discharge pipe	Continuous, high pressure	20	40
		Continuous, low pressure	17	14
		Intermittent, high pressure	10	24
		Intermittent, low pressure	9	6
November-December 1974	Collection pit	Continuous, high pressure	26	11
January 1975	Collection pit	Continuous, high pressure	7	9
April 1975	Collection pit	Continuous, high pressure	35	71

Table 8. (continued)

Period	Collection point	Operating mode and screenwash pressure	% Survival of white perch	% Survival of striped bass
November-December 1974	Discharge pipe	Continuous, high pressure	23	19
March-May 1975	Discharge pipe	Continuous, high pressure	7	61
March 1975	Discharge pipe	Intermittent, 2-hr hold, high pressure	5	5
March-April 1975	Discharge pipe	Intermittent, 4-hr hold, high pressure	0	0

CORRELATION BETWEEN WHITE PERCH SURVIVAL AND STRIPED BASS SURVIVAL OVER ALL EXPERIMENTAL CONDITIONS

$$r = 0.64$$

$$\text{Student's } t \text{ (13 df)} = 3.02$$

$$P < 0.01$$

survival or higher. But in many of the experiments, in particular in the April-May 1977 experiments at Roseton, survival of white perch impinged during intermittent operation with a two-hour wash cycle has been as high as or higher than that of fish impinged during continuous operation. The lowest white perch survival at both Roseton and Danskammer has been observed during intermittent operation with a four-hour cycle.

The results of tests designed to measure the effect of screenwash pressure on survival have also differed from plant to plant. As was noted in our discussion of Atlantic tomcod survival, "low" pressure at Roseton (50 psi) is nearly as high as "high" pressure at Bowline (50 to 60 psi). Most of the tests at Roseton have indicated that under both continuous and intermittent operation white perch survival is higher at 50 psi screenwash pressure than at 100 psi. EA has stated this conclusion both in Exhibit UT-6 (p. 10.3-35) and in the 1977 Progress Report to Central Hudson (Ecological Analysts 1977, p. 5-1). Based on the data in Table 6, I agree with this conclusion.

At Bowline, no increase in survival has been noted when screenwash pressure is reduced from the normal 60 psi to 20 psi or less. EA found no significant effect of pressure on survival under either continuous or intermittent travelling screen operation. EA offered two possible explanations (Exhibit UT-7, pp. 10.3-26-28):

- ... The absence of an apparent effect of screenwash pressure has at least two possible interpretations. First, the damage incurred by the white perch from being washed off the screens may be negligible at screenwash pressures of 50-60 psi and below. Second, the spray from the low pressure system may have been insufficient to remove fish from the screens. As a result, the fish may have been exposed to the high pressure nozzles located just above the low pressure system. In this case pressure exposures would have been similar in both the low and high pressure wash tests.

Although EA found no statistically significant difference, the January-December 1976 survival percentages in Table 8 suggest that the low-pressure screenwash system may actually reduce the survival of white perch and striped bass. In eight cases in which it is possible to compare results obtained under conditions that were identical except for screenwash pressure (i.e., same collecting location, screenwash schedule, and species), higher survival was observed in every case among fish exposed only to the high pressure spray. If screenwash pressure has no effect on survival, then the probability of this result is the same as the probability of tossing a coin eight times and observing eight "heads." Such a result would be expected by chance only 0.4% ( $= 0.5^8$ ) of the time.

Neither EA nor LMS has ever reported designing or conducting experiments in order to determine whether the survival of impinged white perch and striped bass varies seasonally. Nonetheless, the data in Tables 6 and 7 suggest that such variation does exist. In tests performed during the winter

of 1977 (January-March), EA observed 100% mortality of juvenile white perch under all operating conditions. EA's explanation (Ecological Analysts 1977, p. 4-25) was that these fish are more susceptible to handling and holding stresses when water temperatures are near freezing. I agree that since young white perch already are under stress because of low temperatures, they should be more vulnerable to the additional stress of handling and observation. However, for the exact same reason, they should also be more susceptible to the stress of impingement. Survival of white perch impinged at Bowline during this same period was also low (Table 6). Nearly 2000 impinged white perch were sampled at the Bowline collection pit during January-February 1977. All were obtained while the screens were operating in the continuous mode, i.e., the mode under which the highest survival is obtained. Only 28% of the fish collected when the high pressure spray was used, and only 21% of the fish collected when the low pressure spray was used, survived for as long as 96 hours after collection. Relatively high survival was observed among white perch collected at the Bowline discharge pipe (high pressure spray), but the sample size here was low, only 25 fish. Few impinged striped bass have been collected and observed during the winter. Table 10.3-4 of Exhibit UT-7 lists 35 striped bass as having been collected in January and February of 1976. Only 4 of these (11%) survived for 96 hours. Of 158 striped bass collected by LMS in January 1975, 71% survived for a similar period. The results for striped bass are contradictory and no reasonable conclusions can be drawn from them. The results for white perch suggest, although they are not conclusive, that survival is lower during the winter than during other seasons.

It is now time to address the thorny question of the reliability of the data summarized in Tables 6-8 as estimates of the survival of those white perch and striped bass that are impinged, washed off the screens, and returned to the river rather than collected and observed. It is not possible to reproduce in the laboratory the conditions faced by these fish in their natural habitat. A stunned or otherwise weakened fish is more vulnerable to predators, and these predators may congregate in the vicinity of the screenwash discharge because it provides an abundant supply of prey. Congregations of predators have, in fact, been observed at fish return sites in the Sacramento-San Joaquin estuary (Skinner 1972, California Department of Fish and Game et al. 1978). Moreover, analyses of the stomach contents of these predators indicate that they feed heavily on released fish (Skinner 1972, California Department of Fish and Game et al. 1978). A fish that survives these predators may develop fungal or bacterial infections because of wounds and/or lost scales caused by impingement. Such infections may not be observable in the holding facility because they take longer than 96 hours to develop, or because they are suppressed by biocides (according to p. 10.3-6 of Exhibit UT-6, water used at the Roseton holding facility has occasionally been treated with potassium permanganate in order to reduce the incidence of infections).

On the other hand, the collection and holding procedure imposes stresses of its own that the impinged fish does not suffer if it is returned directly to the river. It is for this reason that EA has attempted to measure the

mortality of control fish, exposed only to collection and holding, at all three plants. The control survival data for striped bass and white perch are summarized, respectively, in Tables 6 and 7.

EA's results indicate that for both of these species handling mortality is substantial. The survival of white perch and striped bass controls at Bowline has been no better than that of the comparable impinged fish. Survival of impinged striped bass sampled at the collection pit in 1976 ranged from 14 to 62%. Survival of the corresponding control fish was 32%. Survival of yearling and adult white perch controls was high (86%), but there are no impinged fish with which they can be compared. White perch survival at the Bowline discharge pipe in 1976 ranged from 9 to 20%. The corresponding control survival was 14%. White perch controls at Roseton and Danskammer have fared better, although mortality has been fairly high among young-of-the-year controls. In only one case (Roseton, April-May 1977, young-of-the-year, continuous high-pressure screenwash) has mortality among impinged fish been higher than that of control fish.

Is it possible that all of the observed mortality among impinged fish is caused by collection and handling? I do not believe so. If all mortality were due to collection and handling, then no effects of screenwash procedure on survival could be observed. If, as appears to be the case, collection and holding cause substantial mortality, then EA's procedure ensures that control fish will suffer more of this mortality than will impinged fish. According to p. 10.3-18 of Exhibit UT-7, control fish are held for at least 72 hours before use in impingement survival experiments. If the holding system stresses fish, then controls are exposed to this stress for much longer than are impinged fish. It may, however, be the collection process itself that imposes the stress. Dr. Jinks stated (transcript p. 4599) that the length of time spent in the collection basket influences the survival of control fish. At all three plants control fish are inserted into the collection device at the beginning of the sampling period and left there for the entire sampling period (transcript pp. 4598-99). If impinged fish arrive in the net more or less continuously throughout the sampling period, then each control fish is exposed to the stress of collection for twice as long as the average impinged fish. In addition, control fish suffer a stress that is not imposed at all on impinged fish: stress due to marking. TI has found (transcript, pp. 4597-98) that marking does induce mortality. TI's mark/recapture population estimates are adjusted to account for this mortality. EA has not attempted to measure the effect of marking on the survival of control fish used in impingement survival studies.

Because control fish suffer more collection, handling (including marking), and holding stress than do impinged fish, I do not believe that the mortality of the control fish is a reliable measure of the true sampling/observation mortality suffered by impinged fish. The control survival percentages should not be used to compute adjusted impingement survival percentages (e.g., as is done in Table 10.3-7 of Exhibit UT-6). It may be concluded that the results tabulated in Tables 6-8 represent over-estimates of the actual fraction of impinged white perch and striped bass

that die as a direct result of being impinged. However, an additional fraction, one that cannot be estimated at this time, probably die indirectly because of increased vulnerability to predators or pathogens.

## 2.5 COMPARISON BETWEEN IMPINGEMENT SURVIVAL AND COLLECTION EFFICIENCY

Is the percent survival of Atlantic tomcod, clupeids, white perch, or striped bass impinged and returned to the river under normal operating conditions high enough to offset the effects of collection efficiency? I believe that for Atlantic tomcod impinged at Bowline, Roseton, and Danskammer, the answer to this question is "yes." For clupeids the answer is definitely "no," and for white perch and striped bass it is "probably yes."

Survival of adult Atlantic tomcod impinged during the fall and winter is clearly high enough to offset the effects of collection efficiency. Except for the anomalously low survival observed at Roseton and Danskammer in 1975, the survival of these fish has been very high. In experiments in which 10 or more fish have been collected, at least 70% have survived to the end of the observation period. Fall and winter impingement estimates for this species must be scaled down to account for this high survival. Based on the scant evidence available to date, the survival of juvenile Atlantic tomcod impinged at Bowline, Roseton, and Danskammer during the summer months appears to be high enough to offset collection efficiency, but not so high that downward adjustments are judged to be required.

The survival of impinged clupeids at the three plants discussed in this section appears to be virtually zero, and thus, collection efficiency is not at all offset.

For white perch and striped bass my conclusions are more uncertain. The highest survivals of these species at all three plants have been obtained under continuous travelling screen rotation and, at least at Roseton, low screenwash pressure. These are not the standard operating conditions at any of these plants (Table 3). At Roseton and Danskammer, the most relevant results in Tables 6-8 are those obtained from experiments conducted under intermittent screenwash with the high-pressure spray. Survival percentages under these conditions have ranged from 0 to 25% at Roseton and from 0 to 40% at Danskammer. During conditions of high debris loading or icing, the travelling screens at Roseton are rotated continuously and washed with the high pressure spray. The survival percentages obtained under this operating mode have ranged from 0-51%. At Bowline, both intermittent and continuous rotation have been employed during normal operation. Survival percentages ranging from 0 to 71% have been obtained from the collection pit experiments, with most of the observations falling between 10 and 40%. The generally lower survivals obtained at the Bowline discharge pipe are largely a function of sampling mortality, as evidenced by the relatively poor survival of the discharge pipe controls.

Given that a substantial fraction of the mortality observed among white perch and striped bass is caused by collection and/or observation, it is conceivable that as many as 40% may survive the immediate effects of impingement if returned directly to the river. At all three plants impingement abundance collections are made at least once a week. On these days no fish are returned to the river. Moreover, it is normal procedure at Bowline to hold all fish impinged during the 24 hours preceding an impingement sample. If, on the average, 40% of the fish returned to the river survive, then about 29% ( $40\% \times 5/7$ ) of all white perch and striped bass impinged at Bowline during a week would survive. At Roseton and Danskammer, about 34% ( $40\% \times 6/7$ ) would survive. These survival percentages are enough to offset the effects of collection efficiency (70 to 75%) so that no adjustments of the white perch and striped bass impingement totals need be made.

The possibility remains that survival of impinged striped bass and white perch may be lower during the winter, a season of high impingement at Bowline and Indian Point and of low impingement at Roseton and Danskammer. It is also possible that, due to the effects of sampling mortality, the survival of these species may be higher than is indicated by the results of the experiments. However, biases introduced into the direct impact assessments by underestimating or overestimating the survival of impinged white perch and striped bass at Bowline, Roseton, and Danskammer are likely to be small in comparison to biases introduced by errors in the estimates of population size and total mortality.

It can be seen from Table 3 that travelling screen operating conditions at Albany are similar to those at Bowline, Roseton, and Danskammer. Therefore, it seems reasonable to assume that the survival of impinged fish at this plant is probably similar to that observed at the three plants where studies have been conducted. At Lovett, however, the screens are rotated only once every eight hours. Since reduced survival has been observed at other plants when a four-hour screenwash cycle is employed, it is reasonable to suppose that survival would be even lower with an eight-hour cycle. In the absence of data relating to the mortality of impinged fish at Lovett, I assume zero survival of all species at this plant, and thus, collection efficiency is not at all offset.

### 3. CONCLUSIONS

I conclude, on the basis of an analysis of the four potential biases discussed in Section 2, that the impingement estimates for some species at some plants require adjustment. Table 9 summarizes my estimates by plant and species of the magnitude of biases associated with collection efficiency, reimpingement, impingement on inoperative screens, and impingement survival. Any adjustment factors that I believe are necessary are also presented in Table 9. Since the various biases, in particular those due to impingement survival, cannot be measured precisely, I have chosen to adjust the impingement totals only in cases where there is a clear imbalance between those biases that cause underestimates (collection efficiency and impingement on inoperative screens) and those that cause overestimates (reimpingement and impingement survival). I have applied adjustment factors only if a change of 20% or more in the impingement estimates would result. Adjusting these estimates by smaller amounts is, in my opinion, attributing greater accuracy and precision to the bias measurements than they actually possess.

No estimates of collection efficiency are available for Danskammer, and no estimates of any of the biases are available for Lovett or Albany. In these cases I have estimated the magnitude of the biases from the data obtained at other plants, primarily Roseton and Indian Point Unit 3. Like Roseton and Indian Point (and unlike Bowline), Danskammer, Lovett, and Albany withdraw cooling water directly from the river. As it seems most probable that the slightly higher collection efficiency and reimpingement observed at Bowline are related to the unique intake configuration of that plant, we have assumed that the estimates of collection efficiency at Roseton and Indian Point Unit 3 (both about 70%) and of reimpingement at Roseton (essentially zero) are applicable to these other three plants. The low collection efficiency at Indian Point Unit 2 is undoubtedly caused by the presence of fixed screens in front of the travelling screens, a configuration that exists at no other plant on the Hudson River (except for Indian Point Unit 1, which is not presently operating).

Travelling screen operating procedures at Albany appear to be similar to those at Bowline, Roseton, and Danskammer; therefore, I assume that the same estimates of impingement survival are applicable. At Lovett the screens are rotated only once every eight hours. On the basis of the observed inverse relationship between impingement survival and travelling screen holding time, I assume that no fish survive impingement at Lovett. Since fish impinged at Indian Point are not returned to the river, no survival is possible.

I believe that upward adjustment is required for clupeid impingement estimates at all plants and for impingement estimates for all species at Lovett and Indian Point. My adjustment factor for Indian Point Unit 3 is slightly higher than that used by the utilities because my estimate of collection efficiency is lower. My adjustment factor for Indian Point Unit 2 is identical to that of the utilities. I believe that estimates of

Table 9. Adjustment factors derived for impingement estimates at Hudson River power plants

Plant	Collection efficiency	Reimpingement	Impingement survival		Adjustment factor <sup>a,b</sup>	
			May-August	September-April	May-August	September-April
ATLANTIC TOMCOD						
Bowline	0.75	0.1	0.4	0.7	--	0.6
Lovett	0.70	0	0	0	1.4	1.4
IP unit 2	0.15	0	0	0	6.7	6.7
IP unit 3	0.70	0	0	0	1.4	1.4
Roseton	0.70	0	0.4	0.7	--	0.6
Danskammer	0.70	0	0.4	0.7	00	0.6
Albany (1974-75)	0.70	0	0.4	0.7	--	0.7
Albany (1975-76)	0.70	0	0.4	0.7	--	0.5
CLUPEIDS						
Bowline	0.75	0.1		0		--
Lovett	0.70	0		0		1.4
IP unit 2	0.15	0		0		6.7
IP unit 3	0.70	0		0		1.4
Roseton	0.70	0		0		1.4
Danskammer	0.70	0		0		1.4
Albany	0.70	0		0		1.4
WHITE PERCH AND STRIPED BASS						
Bowline	0.75	0.1		0.4		--
Lovett	0.70	0		0		1.4
IP unit 2	0.15	0		0		6.7
IP unit 3	0.70	0		0		1.4
Roseton	0.70	0		0.4		--
Danskammer	0.70	0		0.4		--
Albany	0.70	0		0.4		--

<sup>a</sup>Adjustment factor = (1/collection efficiency) x (1 - reimpingement) x (1 - impingement survival x the fraction of days on which impinged fish are returned to the river). For Bowline this fraction is equal to 5/7, since impinged fish are collected and held for 24 hours prior to each weekly impingement collection (Exhibit UT-7). For Roseton and Danskammer, it is equal to 6/7, since there is no 24 hour prewash prior to each week's sampling (Exhibit UT-6). For Albany, this fraction is equal to 5/7 for the period April 1974-March 1975, since impingement collections were made twice per week. For the period April 1975-March 1976, it is equal to 13/14, since impingement collections were made only once every two weeks (Lawler et al. 1976b).

<sup>b</sup>Adjustment factors are actually applied to the impingement estimates only if a change of 20% or more would result, that is only adjustment factors less than or equal to 0.80 or greater than or equal to 1.20 are applied.

fall and winter impingement of Atlantic tomcod at Bowline, Roseton, Danskammer, and Albany require downward adjustment because of high survival. Survival of younger tomcod impinged during the warmer months is apparently lower, and therefore, I apply no adjustment to impingement estimates for the months of May-August.

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CHAPTER II

EVALUATION OF IMPINGEMENT LOSSES OF WHITE PERCH  
AT HUDSON RIVER POWER PLANTS

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## SUMMARY AND CONCLUSIONS

This testimony presents two independent lines of evidence evaluating impingement losses of white perch at the power plants on the Hudson River. The first line of evidence involves analyzing the variation in collection rate among years over the period 1972 - 1977. The second line of evidence involves estimating the conditional mortality rate (or equivalently, the percent reduction in year-class strength in the absence of compensation) due to impingement for the 1974 and 1975 year classes.

The collection rates provide estimates of year-class strength on a relative scale. As such, they reflect the effect of entrainment and impingement losses during the preceding months, as well as the effect of any compensatory mechanisms which might alter survival during the preceding months. Regression analyses on collection rates of impinged young-of-the-year white perch among years suggest that there has been no systematic change in the size of the white perch population during the period 1972 - 1977. In particular, there is little evidence of a statistically significant downward trend. However, given the large variability in collection rates used in these regressions, the time series are relatively short (i.e., 5 to 6 years), and thus, the statistical power of the test for a trend is not high. In addition, because of the age of sexual maturity for females and the multiple age-class composition of the spawning population of females, and because impingement mortality increased appreciably starting in 1973 and 1974, a systematic decrease in year-class strength due to impingement mortality would only start to manifest itself with the 1977 (or 1978) and subsequent year classes.

Our estimates of percent reduction in year-class strength due to impingement indicate that the level of impingement impact was probably greater than 20% for the 1974 year class and was probably greater than 15% for the 1975 year class. These estimates do not include consideration of entrainment, so that the total power plant conditional mortality rate is obviously greater than the values presented in this testimony for impingement only. Given the information presently available, it is our judgment that this level of impingement impact is not acceptable from the point of view of the white perch population.

In terms of the comparability of assumptions and values for input parameters used in the utilities' methodology and in ORNL's methodology, the utilities' estimate of percent reduction due to impingement for the 1974 year class of 11.3% is best compared to ORNL's estimate of 25.5%. Five reasons for this more than factor-of-two difference are discussed. The utilities' choice at every one of these five "decision points" affects the results in the same direction, namely, to lower the estimate of percent reduction. ORNL's choice at each of these five decision points is scientifically more sound and defensible.



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## 1. INTRODUCTION

Oak Ridge National Laboratory (ORNL) performed a preliminary evaluation of impingement losses of white perch at the Indian Point Nuclear Station and other Hudson River power plants in preparing the Final Environmental Statement for Indian Point 3 (USNRC 1975). In that evaluation we stated

A 1973 field-tagging study by a consultant for the applicant indicates that the September-October population estimates to be used for planning purposes should be 23 million white perch for the entire Hudson River. This population estimate includes all age groups and not just young-of-the-year, but the young-of-the-year account for the majority of the white perch impinged. This population estimate is tentative, it may vary by an order of magnitude from year to year, and it is based on 1973 data (whereas the impingement estimates are based on 1971-1972 data); nevertheless, the staff feels that impingement may have a significant impact on the white perch population. For example, the projected total impingement loss at all plants with once-through cooling at the three Indian Point Units is 4.1 million white perch per year. If the assumptions are made that these are all young-of-the-year and that 80% of the total white perch population of 23 million are young-of-the-year, then 20% to 25% of these young-of-the-year white perch will be impinged.  
(p. V-61)

In response to the above concern, the Office of Nuclear Regulatory Research, U. S. Nuclear Regulatory Commission, funded research at ORNL starting in May 1978 with the following objectives: To determine the significance of impingement losses on the white perch population at the Indian Point Nuclear Station (all units). To collect, compile, and analyze data and information on white perch impingement losses in the Hudson River. To estimate the impingement exploitation rate by power stations and the conditional rate of mortality due to impingement for the Hudson River white perch population. To document in a final report the results of the analysis and to make a determination whether the impingement losses are having a potentially adverse impact on populations of white perch in the Hudson River.

This report is organized as follows: Section 2 deals with the white perch impingement data per se, including a description of the data base and the analyses of variations in the collection rates among years, months, and power plants. Section III deals with white perch population data, including estimates of population size and monthly natural mortality rates. Section IV integrates the results from Sections 2 and 3 to estimate the conditional mortality rate and exploitation rate due to impingement, using the ORNL empirical impingement model. Section 5 is a discussion of our results in light of the utilities' results and concludes with consideration of whether impingement of white perch at Hudson River power plants is a problem.

## 2. WHITE PERCH IMPINGEMENT DATA

In this section, we first present a brief description of the data base on number of white perch impinged (collected) and on the collection rates at each power plant. Then, we present the results of our analyses of these collection rates, focusing on the pattern of variation among years, months, and power plants. Our analysis of the variation in collection rate of young-of-the-year white perch among years addresses the question of whether there has been a statistically significant and systematic trend in the size of year classes during the period 1972 - 1977. Our analysis of the variation in collection rate among months focuses on how these variations depend on location of the power plant and age of the white perch. Finally, our analysis of the variation in collection rate among power plants focuses on identifying which power plants have the highest and lowest collection rates and how the rankings of power plants depend on the age of the white perch impinged.

### A. Description of the Data Base

Data on number collected and collection rate have been compiled for white perch by month for all years for which data were obtainable for each of the following power plants (moving downriver): Albany, Danskammer, Roseton, Indian Point Units 1, 2, and 3, Lovett, Bowline, and Astoria. These data are presented in the Appendix, Tables A-1 through A-9. Collection rate is defined as the number of impinged white perch counted (Indian Point) or estimated (all other power plants) to be impinged at the intake per unit intake flow. Except for Indian Point, where collection rates were adjusted upward to correct for less than 100% collection efficiency, collection rate is assumed to be approximately equivalent to impingement rate, which is defined as the number of white perch killed at the intake per unit intake flow. A detailed analysis of factors that influence impingement estimates at Hudson River power plants is given in Exhibit EPA-205, including adjustment factors. We designated May 31 - June 1 (a one-day interval) as the dividing line between 12-month old young-of-the-year and 13-month old yearlings.

### B. Variation in Collection Rate Among Years

Collection-rate data are available on a monthly basis for a period of 4-6 years for Bowline, Lovett, Indian Point 2, Roseton, and Danskammer. We have treated collection rate, which is equivalent to a catch per unit effort (CPUE), as an approximate index of population size. In order for a CPUE index to serve as an accurate index of population size, there must be some assurance that actual variations in effort are measured. We believe that data on power plant intake flow (= effort) satisfies this condition, since the uncertainty associated with estimates of intake flow is relatively small. Given this assumption, we have examined the time series of collection rates over years for trends in population size. The regression

model used was  $Y = a + bX$ , where  $Y$  is the collection rate for young-of-the-year (yoy) white perch (RATE0 in Appendix),  $X$  is year,  $a$  is the Y-axis intercept, and  $b$  is the slope. A slope ( $b$ ) significantly greater than 0.0 ( $P < 0.10$ ) suggests an increasing trend over years in population size, while a slope significantly less than 0.0 suggests a decreasing trend in population size. A slope not significantly different from 0.0 indicates that, although year-class strength may have varied, there was no systematic trend in year-class strength over the period 1972 (or 1973) - 1977. The regression analysis was performed for each of the above five power plants and for all five power plants combined for each month separately. The reason for performing individual regressions for each power plant and month was to examine the possibility that there might be consistent patterns of variation at a power plant for certain months which were masked by averaging over power plants or over months. The regression analysis was also performed using the mean annual collection rate, which was calculated as the average of the twelve monthly collection rates for each year. In all, 78 regressions were performed. Because the twelve monthly collection rates are used to calculate the mean annual collection rate for each year, however, this set of regressions cannot be treated rigorously as a set of 78 statistically independent regressions.

The results of these regression analyses are presented in Table 1. Of the 78 regressions, the slope ( $b$ ) differs significantly ( $P < 0.10$ ) from 0.0 in only 8 cases. Of these 8 cases, the slope is significantly greater than 0.0 seven times and less than 0.0 only once (Lovett, in March). In our judgment the mean annual collection rates for each of the five power plants and for all five plants combined are likely to be more reliable indices of population size than the monthly collection rates, which are more subject to variation from year to year due to temperature or salinity differences, and consequently, to differences in the spatial distribution of yoy white perch in the Hudson River, rather than due to real differences in year-class strength. None of the slopes for the six "annual" regressions differs significantly from zero. Thus, the collection rate data from these five power plants suggest that there has been no systematic change in the size of the white perch population during the period 1973 - 1977 (1972 - 1977 for Danskammer).

Because of the age of sexual maturity for females and the multiple age-class composition of the spawning population of females, and because impingement mortality increased appreciably starting in 1973 and 1974, a systematic decrease in year-class strength due to impingement mortality would only start to manifest itself with the 1977 (or 1978) and subsequent year classes. Female white perch collected in the Indian Point region in May 1973 indicated 24% sexual maturity at age 2, 96% at age 3, 92% at age 4, and 100% at age 5 and older (Texas Instruments, 1975a, p. VII-22). The large increases in power plant intake flow occurred during 1973-1975 (Christensen et al. 1976, Fig. 6). Thus, the year classes spawned during these years were spawned by year classes that were not themselves subjected to the increased levels of impingement mortality. Assuming a median age of reproduction of 4 years, only starting in 1977 or 1978 would the compounding

Table 1. Summary of results from regression analyses to examine the time series of collection rates for trends in the Hudson River young-of-the-year white perch population<sup>a</sup>

Month	Bowline				Lovett				Indian Point 2			
	N	r <sup>2</sup>	b	P	N	r <sup>2</sup>	b	P	N	r <sup>2</sup>	b	P
January	5	0.06	-84.5	0.68	5	0.60	208.	0.12	5	0.53	5810.	0.16
February	5	0.17	-95.1	0.49	5	0.27	95.7	0.37	5	0.44	11539.	0.22
March	5	0.21	-80.6	0.44	4	0.88	-29.8	0.06*	5	0.12	-565.	0.57
April	5	0.11	-75.7	0.58	5	0.11	-39.5	0.59	5	0.02	349.	0.82
May	5	0.53	-24.0	0.16	5	0.37	-23.1	0.27	4	0.21	-462.	0.54
June	5	0.00	0.00	-	5	0.00	0.00	-	5	0.00	0.00	-
July	5	0.05	-1.00	0.71	5	0.00	-0.02	0.99	4	0.63	8.49	0.21
August	5	0.26	13.2	0.38	5	0.25	-8.09	0.39	4	0.14	93.2	0.63
September	5	0.03	0.52	0.79	5	0.02	-0.65	0.82	5	0.04	28.5	0.75
October	5	0.26	7.42	0.39	5	0.35	33.3	0.29	5	0.81	534.	0.04*
November	5	0.16	65.2	0.51	5	0.71	93.6	0.07*	5	0.59	1795.	0.13
December	5	0.06	81.1	0.70	5	0.15	45.8	0.52	4	0.63	5625.	0.20
Annual	5	0.05	-16.1	0.72	4	0.67	29.9	0.18	4	0.74	2335.	0.14

Month	Roseton				Danskammer				All Five Plants			
	N	r <sup>2</sup>	b	P	N	r <sup>2</sup>	b	P	N	r <sup>2</sup>	b	P
January	4	0.83	4.65	0.09*	6	0.25	2.23	0.31	5	0.52	1149.	0.17
February	4	0.24	4.05	0.51	6	0.27	2.26	0.29	5	0.42	2261.	0.24
March	4	0.88	12.7	0.06*	6	0.54	13.0	0.10*	5	0.21	-216.	0.44
April	4	0.21	55.7	0.54	6	0.48	121.	0.13	5	0.01	33.5	0.90
May	4	0.37	77.1	0.39	6	0.08	36.0	0.58	5	0.21	-96.9	0.43
June	4	0.00	0.00	-	6	0.00	0.00	-	5	0.00	0.00	-
July	5	0.01	0.033	0.85	6	0.44	-2.82	0.15	5	0.00	-0.247	0.91
August	5	0.26	17.8	0.38	6	0.36	-14.8	0.21	5	0.06	13.4	0.68
September	5	0.42	-59.8	0.23	6	0.19	-8.83	0.39	5	0.06	-7.05	0.70
October	5	0.34	-80.8	0.30	6	0.10	25.2	0.54	5	0.84	108.	0.03*
November	5	0.04	23.7	0.76	6	0.26	109.	0.30	5	0.79	419.	0.04*
December	5	0.01	-1.67	0.87	6	0.03	-4.01	0.73	5	0.05	255.	0.73
Annual	4	0.49	14.8	0.30	6	0.40	23.2	0.18	4	0.45	402.	0.33

<sup>a</sup>The regression model used was  $Y = a + bX$ , where Y is collection rate for yoy white perch and X is year. N is the number of data points (i.e., number of years). r<sup>2</sup> is the coefficient of determination (i.e., the fraction of variability in Y values accounted for by X). b is the slope of the straight line. P is the probability of obtaining a slope this steep (either positive or negative) if the true slope is 0.0. P values ≤ 0.10 are indicated by an asteriak (\*).

effect of entrainment and impingement mortality have an opportunity to manifest itself in reducing year-class strength.

The variability in the collection rate data already available can be used as a guideline to estimate how much of a reduction in population size (and for how many years) would be required in order to detect it statistically (i.e., statistical power of the test). However, assuming that a statistically significant decrease did occur, independent evidence indicating the same result would be required to demonstrate conclusively that such a decrease was related to "overfishing" by the power plants (Christensen et al. 1976).

#### C. Variation in Collection Rate Among Months

Variations in mean collection rate among months are highlighted in Table 2 for young-of-the-year white perch and in Table 3 for yearling and older white perch. The pattern among months depends quite noticeably on location. In particular, at the downriver plants (Astoria, Bowline, Lovett, and Indian Point), collection rates of white perch of all ages are highest during the months of December, January, and February, with the months of November, March, and April also being quite high on occasion. In contrast, at the upriver plants (Roseton, Danskammer, and Albany) collection rates of white perch of all ages indicate two peaks, one in April and May and a second in September, October, and November. Collection rates of yearling and older white perch also tend to be relatively high at a number of the power plants in June (Table 3), which in part is an artifact due to designating May 31 - June 1 (a one-day interval) as the dividing line between 12-month old young-of-the-year and 13-month old yearlings.

#### D. Variation in Collection Rate Among Power Plants

Variation among power plants in the mean annual collection rate is surprisingly great (Tables 2 and 3, last column). Although data are available for only one year at Astoria, and there is no way to estimate from the data reported the collection rates for yoy and older white perch separately, it is evident that relatively few white perch are impinged at Astoria. At the other geographical extreme, it is evident that impingement of yoy white perch is relatively low at Albany compared to the other plants (Table 2), but Albany ranks third out of eight power plants with respect to the impingement of yearling and older white perch (Table 3). In fact, at Albany the impingement of yearling and older white perch is appreciably higher in absolute numbers than for yoy white perch.

For Bowline, Lovett, Indian Point, Roseton, and Danskammer, impingement of yoy white perch is higher in absolute numbers than impingement of older white perch. The values for Indian Point Unit 2 are appreciably higher than those for any other plant (see Table 2). Although the values for Indian Point Unit 1 are also high, impingement of fish at Unit 1 is not presently

Table 2. Variation in mean collection rate of young-of-the-year white perch among months and among power plants<sup>a</sup>

Plant	Location <sup>b</sup>	Number of years of data	June	July	August	September	October	November	December	January	February	March	April	May	Annual
Astoria <sup>c</sup>	East River	1							6.9 (1)		4.6 (2)		3.1 (3)		1.8 (9)
Bowline	37.5	5							767.1 (1)	553.6 (3)		332.9 (4)	577.9 (2)		248.0 (4)
Lovett	42	5						394.8 (2)	273.9 (4)	558.0 (1)			315.7 (3)		177.2 (5)
Indian Point Unit 1	43	2-4							3415.3 (2)	2542.9 (4)	4196.6 (1)		3219.2 (3)		1563.7 (2)
Indian Point Unit 2	43	4-6							7942.4 (3)	12610.4 (2)	18101.3 (1)		5822.8 (4)		4565.6 (1)
Indian Point Unit 3	43	1-3						1286.7 (3)	646.0 (4)	1836.2 (2)	2973.2 (1)				666.5 (3)
Roseton	65.4	4-5					246.8 (2)	286.5 (1)					149.6 (4)	233.5 (3)	97.5 (7)
Danskammer	66	6					413.0 (2)	482.9 (1)					304.0 (4)	305.9 (3)	153.2 (6)
Albany <sup>d</sup>	140	2				20.8 (2)	7.7 (3)						7.7 (4)	26.3 (1)	6.24 (8)

<sup>a</sup>Based on analysis of RATEO values in Tables A-1 through A-9 in Appendix A. The top number of each pair of numbers in the table is the mean collection rate (number of fish collected per million cubic meters). The bottom number of each pair (in parentheses) is the ranking for that mean collection rate, with one (1) denoting the highest rate. The mean monthly collection rates are averages over all years for which estimates for that month were available; these mean monthly rates were ranked from 1 to 12 for each power plant, but only entries for the four highest months are given in this table. The mean annual collection rate for each power plant is the average of the 12 mean monthly rates; these mean annual rates were ranked from 1 to 9 over power plants.

<sup>b</sup>River mile (RM) on the Hudson River, with RM 0 at the Battery.

<sup>c</sup>All ages combined at Astoria.

<sup>d</sup>Based on RATEO values in Table A-1 in the Appendix only for the period April 1974 - March 1976.

Table 3. Variation in mean collection rate of yearling and older white perch among months and among power plants<sup>a</sup>

Plant	Location <sup>b</sup>	Number of years of data	June	July	August	September	October	November	December	January	February	March	April	May	Annual
Bowline	37.5	5								175.3 (1)	87.9 (3)	61.0 (4)	123.1 (2)		46.1 (6)
Lovett	42	5	70.6 (1)					14.3 (3)		35.6 (2)		13.2 (4)			15.2 (8)
Indian Point Unit 1	43	2-4	117.9 (4)						127.5 (3)	162.3 (2)		184.2 (1)			84.6 (4)
Indian Point Unit 2	43	4-6							420.0 (3)	804.9 (1)	515.3 (2)	413.6 (4)			231.9 (1)
Indian Point Unit 3	43	1-3	65.4 (3)						45.3 (4)	117.2 (1)	78.6 (2)				34.4 (7)
Roseton	65.4	4-5	55.7 (3)					50.5 (4)					164.5 (1)	155.4 (2)	48.0 (5)
Danskammar	66	6	312.9 (1)	164.9 (4)									273.4 (2)	208.7 (3)	101.4 (2)
Albany <sup>c</sup>	140	2	164.1 (4)	212.0 (2)		218.2 (1)	211.6 (3)								90.9 (3)

<sup>a</sup>Based on analysis of RATE1 values in Tables A-1 through A-9 in Appendix A. The top number of each pair of numbers in the table is the mean collection rate (number of fish collected per million cubic meters). The bottom number of each pair (in parentheses) is the ranking for that mean collection rate, with one (1) denoting the highest rate. The mean monthly collection rates are averages over all years for which estimates for that month were available; these mean monthly rates were ranked from 1 to 12 for each power plant, but only entries for the four highest months are given. The mean annual collection rate for each power plant is the average of the 12 mean monthly rates; these mean annual rates were ranked from 1 to 8 over power plants.

<sup>b</sup>River mile (RM) on the Hudson River, with RM 0 at the Battery.

<sup>c</sup>Based on RATE1 values in Table A-1 in the Appendix only for the period April 1974 - March 1976.

of major concern, since the unit is not presently generating electricity. The circulating pumps are generally only operated for experimental purposes (e.g., testing of fine-mesh screens). Impingement of yoy white perch is higher at Bowline and Lovett than at Roseton and Danskammer (Table 2), but the rankings are reversed for impingement of yearling and older white perch (Table 3).

### 3. WHITE PERCH ABUNDANCE AND MORTALITY

#### A. Abundance

No estimates have been made of the absolute abundance of yearling and older white perch in the Hudson, and none of the existing data are adequate for this purpose. However, two independent estimates of the abundance of white perch juveniles are available. The first, or combined gear estimate, is derived from a combination of data from the Texas Instruments (TI) longitudinal ichthyoplankton survey, fall shoals survey, and riverwide beach seine survey. Descriptions of these surveys can be found in the Multiplant Report (TI 1975b) and the Final Research Report (FRR) (Exhibit UT-4 and revisions and errata). A detailed description of the method used to calculate abundances from these data was provided through a response dated February 27, 1978 to an EPA information request dated December 27, 1977. According to that response, Texas Instruments has calculated on a weekly basis the combined gear population estimates for the months of July through December 1974 and on a biweekly basis the estimates for the months of July through December 1975. These data also were provided in the response dated February 27, 1978 to the information request of December 27, 1977.

The second estimate is derived from a mark/recapture program conducted by Texas Instruments. Descriptions of the methods used in data collection and analysis can be found in the Multiplant Report and the FRR. Mark/recapture estimates of white perch juvenile abundance in October 1974 and in October 1975 are presented in a supplement to the FRR (Exhibit UT-3 and revisions and errata). A comparison of the two sets of estimates reveals substantial discrepancies for both years (Table 4). The mark/recapture estimates are far larger than the corresponding combined gear estimates, 14 times as high in 1974 and 6 times as high in 1975. We believe that the mark/recapture estimates are the more reliable of the two sets for reasons discussed below.

The combined gear estimates undoubtedly underestimate the true abundance of white perch, since TI made no corrections for gear efficiency (Exhibit UT-4, Sections 7.9.1.2, 7.9.1.3, and 7.9.1.4). In effect, they assumed that all of the gears (beach seine, epibenthic sled, and Tucker trawl) catch 100% of the fish in their path. In reality, no gear captures 100% of the organisms in its path. Even the smallest larval fishes possess a limited ability to evade capture. Recent tests conducted by Texas Instruments (1978) indicate that the efficiency of the 100-foot beach seine at catching juvenile white perch probably ranges between 7 and 25%. The epibenthic sled and Tucker trawl were designed primarily as ichthyoplankton gear. Since the majority of juvenile white perch are well in excess of 50 mm in length by early August, the efficiency of these gears during the period of interest here (August-December) is probably very low. Although no attempts have been made to quantify the efficiency of the epibenthic sled and Tucker trawl, Kjelson and Johnson (1978) have recently reported that the 6.1-m Otter trawl, which, because of its larger size, is probably more

Table 4. Estimates of white perch juvenile abundance in the Hudson River<sup>a</sup>

	October, 1974	October, 1975
Combined gear estimate <sup>b</sup>	1.5 x 10 <sup>6</sup>	5.0 x 10 <sup>6</sup>
Mark/recapture estimate <sup>c</sup>	21 x 10 <sup>6</sup>	30 x 10 <sup>6</sup>

<sup>a</sup>Regions included in the combined gear estimates were RM 24-61 (KM 38-98) in 1974 and RM 14-76 (KM 22-122) in 1975. The region included in the mark/recapture estimates was RM 12-152 (KM 19-243) during both years.

<sup>b</sup>Based on extrapolation from beach seine and epibenthic sled data. Value for 1974 is mean of five weekly estimates. Value for 1975 is mean of 3 biweekly estimates.

<sup>c</sup>Based on fish released in the fall and recaptured the following spring.

efficient than either of the above gears at catching juvenile fish, is only about 30-50% efficient.

An additional source of error in the combined gear estimates for white perch is the design of the sampling program itself. As described in the Multiplant Report (Section 3), the longitudinal river survey, fall shoals survey, and the riverwide beach seine survey are all designed for optimal sampling of striped bass. A common result of this design has been the collection of large numbers of samples in regions that contain low densities of white perch, and the collection of few samples in regions containing high densities of white perch. For example, during the period August 19-22, 1974, 34 epibenthic sled tows were conducted in the Tappan Zee region. No white perch were caught. Virtually all of the white perch collected during this period (58 out of 64) came from five tows collected from the shoal stratum of the Cornwall region.

By comparison, the mark/recapture estimates seem to be more free of major biases. Population estimates calculated from mark/recapture data are subject to several sorts of biases (Ricker 1975). Three that seem potentially important in this application, although probably only as minor biases, are: differential mortality of marked and unmarked fish, nonhomogeneous distribution of marked and unmarked fish, and the natural occurrence of "marked" fish.

If marked fish suffer more mortality than unmarked fish, either from the stress imposed by handling and marking or because marked fish are more vulnerable to predators or disease than are unmarked fish, then an overestimate of the true population size can result. TI addressed this problem with experiments conducted in 1973 (described in the Multiplant Report) and derived correction factors to account for short-term (14 days) handling mortality of marked white perch. The possibility that long-term survival of marked white perch under natural conditions may be lower than that of unmarked fish has not been evaluated by TI.

The Peterson method of estimating population size from mark/recapture data, the method chosen by TI, requires that marked fish mix completely with the unmarked population prior to recapture. If this mixing does not occur, a bias can be introduced into the results. In particular, if sampling during the recapture period is concentrated in regions where marked fish are relatively abundant in comparison to their true proportion in the population, then the true population size will be underestimated. In the Multiplant Report, TI cited insufficient mixing as a reason for discarding estimates of the number of juvenile white perch in the Hudson in the fall of 1973. In this case fish were both marked and recaptured in the fall. Insufficient mixing is probably not a problem with the fall 1974 and 1975 estimates, because fish were released in the fall and recaptured during the following spring. From the distributional data presented in Exhibit UT-4 (Section 6.1) and from the seasonal patterns of impingement discussed in Section II of this report, it is evident that white perch juveniles migrate downstream to Haverstraw Bay and the Tappan Zee in the late fall and

overwinter there before returning upstream in the spring. These migrations would appear to provide ample opportunity for mixing.

TI uses finclips to mark juvenile white perch and striped bass. Natural loss of fins is not uncommon, and the mistaking of fish that have lost fins for marked fish can cause underestimates of population size. TI has discovered several such "fin anomalies." According to the Multiplant Report, in 1974 it was discovered that about 0.3% of unmarked juvenile white perch were missing one or both pelvic fins. This finding necessitated the recalculation (by excluding fish marked with single or double pelvic finclips) of mark/recapture estimates for the 1973 year-class. Mark/recapture estimates of the August-September, 1975 abundance of white perch juveniles (Exhibits UT-3, UT-4) were discarded after it was discovered that a mark type (anal finclip) used in the August-September, 1975 release also occurs among unmarked fish. To this date no fin anomalies have been noted that involve any of the finclip types (six marks were used; five of these were double finclips) used in the October-November, 1974 and October, 1975 releases. We presently believe that the Peterson mark/recapture estimates of white perch juvenile abundance in October of 1974 and 1975 are the best available estimates of the abundance of the 1974 and 1975 year-classes. It is these estimates that are used in the direct impact assessment contained in Section IV.

#### B. Mortality

Dew (1978) has used the catch-curve method to calculate an average annual mortality rate for age zero and older white perch (Table 5). His results are derived from bottom trawl data collected in the vicinity of the Bowline Point Generating Station between 1971 and 1976. We believe, however, that age zero fish should not have been used in this analysis, since their mortality is probably higher than that of yearling and older fish. We also believe that Dew's method of analysis was not the most appropriate application of the catch-curve methodology. Dew estimated the annual fractional mortality separately for each age-class, grouping together all fish of age 5 and older. He then averaged the individual estimates (value for A of 0.53 in Table 5). Robson and Chapman (1961) have described an entirely different method of calculating average annual mortality when all fish older than a certain age are grouped together. As Robson and Chapman's method has been proven to be unbiased (whereas Dew's method has not) under the assumptions of the catch-curve method, and since its statistical properties are known (which is not the case with Dew's method), we believe that it is superior to Dew's method. Therefore, we have redone Dew's analysis, excluding the age zero fish and using the method of Robson and Chapman (1961), to calculate an annual mortality rate for yearling and older white perch of approximately 50% (value for A of 0.49 in Table 5). This value is undoubtedly in error to some extent, since the catch-curve method is sensitive to fluctuations in year-class strength (Robson and Chapman, 1961). However, it is in good agreement with values obtained by

Table 5. Catch-curve estimates of white perch mortality based on bottom trawl data from the Bowline Point vicinity, 1971-1976

	Annual fractional mortality (A)	Annual instantaneous mortality rate (Z)
Original values <sup>a</sup> (ages 0 through 5+)	0.5349	0.7655
Recalculated values <sup>b</sup> (ages 1 through 5+)	0.4854	0.6644

<sup>a</sup>Calculated by Dew, 1978.

<sup>b</sup>Recalculated by excluding age 0 fish and using the method of Robson and Chapman, 1961.

Wallace (1971) for age I-IV white perch in the Delaware River: 54% for males and 58% for females. We believe at this time that 50% is a reasonable estimate, and this is the value used in our direct impact assessment.

None of the available data appears adequate for deriving reliable estimates of total mortality in impingeable young-of-the-year white perch. Using the method employed by TI to estimate mortality in juvenile striped bass, we attempted to calculate a mortality rate using TI's weekly combined gear estimates of white perch abundance. The method involves regressing the natural logarithm of the population estimate against time (in days) from the end of July to mid-December. The slope of the regression line is an estimate of the daily instantaneous mortality rate. Using this method we obtained no useful results, because there was no discernible decline in the combined gear estimates between early August and mid-December. We performed a similar analysis using data from only a single gear, the epibenthic sled, and a single sampling program, the fall shoals survey, in the hope of eliminating variation due to pooling different gears and different sampling programs. Although the epibenthic sled samples during the fall shoals survey seemed like the best single source of data from which to derive estimates of total mortality, this analysis was even less successful: population estimates based on epibenthic sled data alone increased between August and December, both in 1974 and in 1975.

We have, therefore, used a range of values for young-of-the-year mortality in our direct impact assessment. As a high estimate we have used the value of 80% assumed in Exhibit UI-3. Given the absence of a seasonal decline in the combined gear and epibenthic sled abundance estimates, this value may be too high. Alternatively, we have assumed that the mortality among impingeable young-of-the-year is identical to that among yearling and older fish, i.e., that the annual fractional mortality of young-of-the-year white perch is about 50%. Since, because of their smaller size, young-of-the-year should be more vulnerable to predators than are older white perch, this value may be too low.

#### 4. ESTIMATION OF CONDITIONAL MORTALITY RATE AND EXPLOITATION RATE DUE TO IMPINGEMENT

The empirical model of impingement impact used to estimate the conditional mortality rate and exploitation rate due to impingement for the Hudson River white perch population is described in Barnthouse et al. (1979). The model requires: (1) estimates of the initial number of young-of-the-year in the Hudson River white perch population at the time they first become vulnerable to impingement, (2) estimates of the rate of either total or natural mortality during the period of vulnerability to impingement, and (3) monthly estimates of the number of white perch impinged by year class.

For the purpose of comparing alternative assumptions about the age of impinged fish, it is desirable to formulate the model in terms of natural rather than total mortality, even though in practice only total mortality can be directly estimated from field data. This is not a major problem, however, since it is possible to calculate the conditional natural mortality rate, given the total mortality rate and the impingement exploitation rate (Barnthouse et al. 1979). In addition, when natural mortality is high relative to impingement mortality, total mortality and natural mortality are nearly numerically identical. For example, the natural conditional mortality rate calculated by Barnthouse et al. (1979) for impingeable young-of-the-year striped bass was 0.79, only slightly smaller than the total mortality rate of 0.8. Similarly, we believe that it is reasonable to use the same value (0.5) as an approximation of both the natural conditional mortality rate and total mortality rate in yearling and older white perch.

The estimates of initial population size and natural mortality rates are given in Table 6, and the bases for these estimates are discussed in the preceding section of this report (Section 3). Monthly estimates of the number of white perch impinged by year class are given in Table 7. These estimates include white perch impinged at all the power plants discussed in Section 2 and in the Appendix, except Astoria. Although impingement data are not available for the Albany power plant except for the period April 1974 - March 1976, Albany was operating continuously during the period June 1974 through December 1977, which is the period considered in this report in estimating conditional mortality rates and exploitation rates due to impingement for the 1974 and 1975 year classes. Consequently, the number of young-of-the-year and older white perch collected at Albany was approximated for each month from April 1976 - December 1977, as described in Table A-1 of the Appendix.

The value of a sexually immature fish to a population increases with its age, because its probability of surviving to sexual maturity increases. For this reason the impact to the population of killing a sexually immature fish increases with its age. If, as the utilities assume, the total mortality of juvenile white perch between July of year 0 and July of year 1 is 80%, then a single yearling impinged in July is worth five juveniles

Table 6. Initial population sizes and mortality estimates used in the empirical model of impingement impact to estimate the conditional mortality rate and exploitation rate due to impingement for the Hudson River white perch population

Initial population size <sup>a</sup>		Natural mortality <sup>b</sup>	Year class	
			1974	1975
P <sub>October 1</sub> <sup>c</sup> (x 10 <sup>6</sup> )	LB		12	21
	BE		21	30
	UB		39	45
P <sub>July 16</sub> <sup>d</sup> (x 10 <sup>6</sup> )	LB	Low	13.9	24.3
		High	16.8	29.4
	BE	Low	24.3	34.7
		High	29.4	41.9
	UB	Low	45.1	52.0
		High	54.5	62.9

<sup>a</sup>BE denotes the best estimate of initial population size. LB and UB denote the lower and upper bounds, respectively, of the 95% confidence interval about the best estimate.

<sup>b</sup>Low natural mortality:  $r_n = 0.001899$  per day for the entire period of vulnerability to impingement. This instantaneous natural mortality rate corresponds to an annual (i.e., 365 days) conditional mortality rate due to all causes of mortality other than impingement of 0.5.

High natural mortality:  $r_n = 0.004409$  per day from July 16 as young-of-the-year to May 31 of the following year just as they become yearlings. This instantaneous natural mortality rate corresponds to an annual (i.e., 365 days) conditional mortality rate due to all causes other than impingement of 0.8.  $r_n = 0.001899$  per day from June 1 as yearlings until the end of the period of vulnerability.

<sup>c</sup>P<sub>October 1</sub> denotes the size of the Hudson River young-of-the-year white perch population on October 1, as estimated by Texas Instruments using mark-recapture techniques (Exhibit UT-3, p. 2-VII-2, as modified by errata).

<sup>d</sup>P<sub>July 16</sub> denotes the size of the Hudson River young-of-the-year white perch population on July 16. It is calculated using the equation

$$P_{\text{July 16}} = P_{\text{October 1}} / \exp(-76 r_n) ,$$

where values for P<sub>October 1</sub> and  $r_n$  are given elsewhere in this table and 76 is the number of days between July 16 and October 1.

Table 7. Monthly estimates of the number of white perch impinged at all the Hudson River power plants combined for the 1974 and 1975 year classes<sup>a</sup>

Age (years)	Month	Year class			
		1974		1975	
		Number of years of vulnerability		Number of years of vulnerability	
		2	3	2	3
0	6	0		0	
	7	3,486		8,898	
	8	14,887		97,910	
	9	26,239		83,980	
	10	112,957		93,888	
	11	245,492		239,150	
	12	607,434		348,596	
	1	415,724		589,206	
	2	270,751		182,891	
	3	139,751		130,261	
	4	609,090		111,820	
	5	91,910		40,151	
1	6	37,242	18,621	27,014	13,507
	7	22,126	11,063	13,835	6,918
	8	14,122	7,061	6,770	3,385
	9	19,924	9,962	13,791	6,896
	10	19,534	9,767	25,676	12,838
	11	28,005	14,002	12,552	6,276
	12	7,803	3,902	48,102	24,051
	1	38,078	19,039	143,010	71,505
	2	9,293	4,646	43,558	21,779
	3	12,444	6,222	49,579	24,790
	4	14,103	7,052	38,692	19,346
	5	7,612	3,806	56,365	28,182
2	6		13,507		35,710
	7		6,918		8,805
	8		3,385		12,662
	9		6,896		8,736
	10		12,838		17,362
	11		6,276		19,145
	12		24,051		10,890
	1		71,505		
	2		21,779		
	3		24,790		
	4		19,346		
	5		28,182		

<sup>a</sup>Monthly values for number of yoy white perch impinged were calculated by summing the NUMBER0 values in Tables A-1, and A-3 through A-9 in Appendix A over power plants for the appropriate month and year.

Monthly values for number of yearling white perch impinged were calculated either by summing the NUMBER1 values over power plants for the appropriate month and year (2 years of vulnerability, corresponding to the assumption that 100% of the yearling and older white perch impinged were yearlings) or by summing the NUMBER1 values over power plants and dividing by 2 (3 years of vulnerability, corresponding to the assumption that 50% of the yearling and older white perch impinged are yearlings).

Monthly values for number of 2-year-old white perch impinged were calculated by summing the NUMBER1 values over power plants, dividing by 2, and tabulating the result for the given month, but one year later (3-years of vulnerability only, corresponding to the assumption that 50% of the yearling and older white perch impinged are 2-year olds).

impinged 12 months earlier. If mortality between year 1 and year 2 is 50%, then each 2-year-old white perch is worth two yearlings or ten young-of-the-year. Even though the number of yearling and older white perch impinged each year constitutes only about 10% of the total white perch impingement, the impact of killing these fish is quite substantial.

As indicated in Table 7, two alternative assumptions were made concerning the age of impinged yearling and older white perch. For one case, it was assumed that all white perch impinged that are yearlings and older are yearlings, resulting in two years of vulnerability to impingement. For the other case, it was assumed that of the yearling and older white perch impinged, 50% were yearlings and 50% were 2-year olds, resulting in three years of vulnerability to impingement. It is our judgment, based on length-frequency data of impinged white perch at Bowline, Indian Point, and Roseton (see Appendix, Tables A-3, A-5, 6 & 7, and A-9), that the true age composition of yearling and older white perch impinged (which includes some white perch older than 2 years), results in an effective split between yearlings and 2-year olds that is between the two assumptions just given, that is, between 100% yearlings - 0% 2-year olds and 50% yearlings - 50% 2-year olds. Because of the lack of 1978 impingement data for January - May, no model estimates of impingement impact assuming three years of vulnerability are given for the 1975 year class.

With this exception, estimates of conditional mortality rate and exploitation rate due to impingement are given in Table 8 for the 1974 and 1975 year classes for combinations of estimates and assumptions involving initial population size (low, best estimate, and high), natural mortality (low and high), and number of years of vulnerability (2 and 3 years).

Estimates of the conditional mortality rate due to impingement are especially relevant in assessing the effects of power plant impingement, since they are equivalent to estimates of the fractional (or percent) reduction in the size of a year class due to impingement, assuming no compensation (see Barnthouse et al. 1979). As indicated by the values in Table 8, percent reduction values (obtained by multiplying by 100) are greater (1) the smaller the initial population size, (2) with high natural mortality rates as opposed to low, and (3) assuming three years of vulnerability instead of two. Furthermore, assuming approximately comparable degrees of uncertainty in the choices of low and high estimates of initial population size, natural mortality, and number of years of vulnerability, it appears that the estimates of percent reduction are most sensitive to (i.e., vary most widely depending on) estimates of initial population size, least sensitive to the number of years of vulnerability assumed, and intermediately sensitive to estimates of natural mortality.

The percent reduction values range from 9.5 - 45% for the 1974 year class and from 7.7 - 24% for the 1975 year class, assuming only two years of vulnerability. Assuming three years of vulnerability, the percent reduction values range from 12-59% for the 1974 year class. For the 1975 year class, percent reduction values cannot be calculated because 1978 impingement data are not presently available.

Table 8. Estimates of conditional mortality rate and exploitation rate (in parentheses) due to impingement for the 1974 and 1975 year classes of the Hudson River white perch population for combinations of estimates and assumptions involving initial population size, natural mortality, and number of years of vulnerability<sup>a</sup>

Number of years of vulnerability <sup>b</sup>	Year class	Initial Population Size <sup>c</sup>					
		Low		Best estimate		High	
		Natural mortality rate <sup>d</sup>		Natural mortality rate <sup>d</sup>		Natural mortality rate <sup>d</sup>	
		Low	High	Low	High	Low	High
2	1974	0.309	0.446	0.177	0.255	0.095	0.137
		(0.165)	(0.200)	(0.094)	(0.114)	(0.051)	(0.061)
	1975	0.166	0.245	0.116	0.172	0.077	0.115
		(0.082)	(0.099)	(0.057)	(0.069)	(0.038)	(0.046)
3	1974	0.387	0.588	0.221	0.336	0.119	0.181
		(0.172)	(0.209)	(0.099)	(0.119)	(0.053)	(0.064)
	1975	--	--	--	--	--	--

<sup>a</sup>Total conditional impingement mortality rate calculated using Eq. (11) in Barnthouse et al. (1979), i.e.,  $m_T = 1 - \prod_{i=1}^{12} (1 - m_i)$ , except with the index  $i$  running from 1 to 24 (2 years of vulnerability) or 1 to 36 (3 years of vulnerability). The individual monthly  $m_i$  values were calculated in sequence using Eq. (2) and then Eq. (10) in Barnthouse et al. (1979). Total conditional impingement mortality rates are equal to fractional (or percent) reductions in year-class strength due to impingement, assuming no compensation.

Exploitation rate calculated by dividing the total number of white perch impinged in a year class during the entire period of vulnerability by the size of the yoy population at the start of the period of vulnerability.

<sup>b</sup>See Table 7.

<sup>c</sup>See Table 6.

<sup>d</sup>See footnote b to Table 6.

Exploitation rates show the same pattern of variation as the conditional mortality rates with respect to values used for initial population size, natural mortality, and number of years of vulnerability (Table 8). The exploitation rates range from 5.1 - 20.0% for the 1974 year class and from 3.8 - 9.9% for the 1975 year class, assuming only two years of vulnerability. Assuming three years of vulnerability, the exploitation rates range from 5.3 - 20.9% for the 1974 year class, and, although they cannot be calculated at this time, they would be expected to be lower for the 1975 year class. As discussed in Barnthouse et al. (1979), because there are competing sources of mortality and each an organism can die only once, an exploitation rate is always lower than the corresponding conditional mortality rate. However, as stated above, it is the conditional mortality rate due to impingement that is equivalent to percent reduction in the size of the year class. Because of this equivalence, the conditional mortality rate is a more meaningful measure of impact than is the exploitation rate.

## 5. DISCUSSION

A. Comparison With Utilities' Results

The utilities have estimated the conditional mortality rate and exploitation rate due to impingement of white perch for the 1974 year class (Table 9).

Impingement impact for the 1974 year class was estimated assuming that 90% of the July 1974-June 1975 impingement consisted of the 1974 year class. Exploitation of this year class was calculated to be 4.4% at Indian Point Unit 2 and 5.9% for the multiplant case (Table 2-VII-1). These exploitation rates are equivalent to conditional mortality rates of 8.5% for Indian Point and 11.2% for multiplant with an assumed total mortality rate of 80%. (Exhibit UT-3, p. 2-VII-3)

In terms of the comparability of assumptions and input values used in the utilities' methodology and our methodology, the utilities' conditional mortality rate of 11.3% and exploitation rate of 5.9% in Table 9 for the multiplant case can be compared with our estimates in Table 8 (two years of vulnerability, best estimate of initial population size, and high natural mortality) of a conditional mortality rate of 25.5% and an exploitation rate of 11.4%. The two sets of estimates differ by approximately a factor of 2 for several reasons (we have not attempted to estimate how much of the two-fold difference is due to each of the following reasons):

- (1) We included the Albany, Danskammer, and Lovett Steam Electric Generating Stations, while they did not. These three plants were operating during the years 1974 - 1977 and were impinging white perch. Thus, they should be included in any evaluation of the impact of impingement on the Hudson River white perch population.
- (2) We included Indian Point Unit 1, which operated continuously (at least the circulating water pumps) from June 1974 through August 1975, while they did not. Since this unit was operating during part of the period of interest and was impinging white perch, it also should be included in any evaluation of the impact of impingement on the Hudson River white perch population.
- (3) Our values reflect two years of vulnerability to impingement, while their values reflect only one year of vulnerability (i.e., they ignored impingement of yearling and older white perch from the 1974 year class past June 1975). Since yearling and older white perch, in fact, are impinged in appreciable numbers, they must be considered as such in any credible evaluation of the impact of impingement on the Hudson River white perch population. There is no scientifically, justifiable methodological reason or biological reason for not including these yearling and older white perch in such an evaluation.

Table 9. Relevant parts of Table 2-VII-1 in Exhibit UT-3

Power plant	Number impinged <sup>a</sup>	Exploitation rate (u)	Conditional mortality (m)
Bowline	473,043	0.0137	0.0273
Roseton	52,025	0.0015	0.0030
Indian Point Unit 2	1,520,317 <sup>b</sup>	0.0441	0.0849
Multiplant	2,045,385	0.0594	0.1126

<sup>a</sup>Total impingement, of which 90% are assumed to be 1974 year class.

<sup>b</sup>Includes 948 impinged at Indian Point Unit 3.

- (4) We used available data to estimate on a monthly and plant-specific basis the percent of white perch impinged from June 1974 - June 1975 that were from the 1974 year class, whereas they assumed 90%. As the PERCENTO values in Tables A-1, and A-3 through A-9 indicate, their assumption of 90% young-of-the-year may be justified for Lovett and for the three Indian Point units. However, the utilities' assumption of 90% young-of-the-year is clearly too high for Albany, Bowline, Danskammer, and Roseton.
- (5) We used the methodology presented in Barnthouse et al. (1979), which permitted us to take into account monthly variations in collection rates, whereas the utilities' methodology implicitly assumes a constant vulnerability. In reality, as discussed in Section II, the collection rate fluctuates appreciably on a monthly basis, with rates being substantially higher from December - May than from June - November (Tables 2 and 3). (Also see Table 3 and associated text in Barnthouse et al. (1979) for a comparison using constant versus variable collection rates to estimate the conditional mortality rate due to impingement.)

The utilities' choices at every one of the above five "decision points" affect the results in the same direction, namely, to lower the estimates of impingement impact. Yet, given that the purpose of the utilities' analysis and of our own analysis ought to be to realistically and objectively estimate the percent reduction in the strength of the 1974 year class of white perch in the Hudson River due to impingement at power plants, our choices at each of the five decision points is scientifically more sound and defensible for the reasons we have given.

#### B. Is there a problem?

This testimony presents two independent lines of evidence evaluating the impingement losses of white perch at the power plants on the Hudson River. The first line of evidence, the analysis of the variation in collection rate among years (Section 2.B), suggests that there is not yet an obvious problem, but that it is too soon to be sure. The second line of evidence, the estimates of conditional mortality rate due to impingement (Section 4), suggests that the level of impingement impact cannot be assessed as acceptable from the point of view of the white perch population. These two lines of evidence are briefly elaborated on in the following two paragraphs.

The collection rates provide estimates of year-class strength on a relative scale. As such, they reflect the effect of entrainment and impingement losses during the preceding months, as well as the effect of any compensatory mechanisms which might alter survival during the preceding months. Regression analyses on collection rates of impinged young-of-the-year white perch suggest that there has been no systematic change in the size of the white perch population during the period 1972 - 1977 (Section 2.B). In particular, there is little evidence of a statistically

significant downward trend. However, given the large variability in collection rates used in these regressions, the time series are relatively short (i.e., 5-6 years), and thus, the statistical power of the test for a trend is not high. In addition, because of the age of sexual maturity for females and the multiple age-class composition of the spawning population of females, and because impingement mortality increased appreciably starting in 1973 and 1974, a systematic decrease in year-class strength due to impingement mortality would only start to manifest itself with the 1977 (or 1978) and subsequent year classes.

The estimates of percent reduction in year-class strength due to impingement that are presented in Table 8 cover a broad range, as discussed in Section 4. Our analysis shows that the level of impingement impact was probably greater than 20% for the 1974 year class and was probably greater than 15% for the 1975 year class. These estimates do not include consideration of entrainment, so that the total power plant conditional mortality rate is obviously greater than the values given here for impingement only. Given the information presently available, it is our judgment that this level of impingement impact is not acceptable from the point of view of the white perch population.

## VI. REFERENCES

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- Exhibit EPA-205. Barnthouse, L. W. 1979. An analysis of factors that influence impingement estimates at Hudson River power plants. Testimony prepared for the U.S. Environmental Protection Agency, Region II.
- Exhibit UT-3. Supplement I to influence of Indian Point Unit 2 and other steam electric generating plants on the Hudson River estuary, with emphasis on striped bass and other fish populations. Edited by J. T. McFadden and J. P. Lawler. Submitted to Consolidated Edison Company of New York, Inc. July 1977. Errata correcting the estimates of the size of the Hudson River young-of-the-year white perch population on October 1, originally given on p. 2-VII-2 of this reference, are contained in Utilities' Exhibits UT-3E-2 and UT-3E-5.
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APPENDIX  
IMPINGEMENT DATA BASE

The data base is presented by power plant,  
arranged in alphabetical order



TABLE A-1

WHITE PERCH IMPINGEMENT DATA FOR THE  
ALBANY STEAM ELECTRIC GENERATING STATION

April 1974 - March 1975: Ref. (1)

RATE	(collection rate): <sup>1</sup> calculated from monthly data on average observed number of fish of all species collected per million gallons of intake flow at all units (from Table 3, Column B, Plant Av.), and monthly data on percentage composition by species of the fish collected (from Table 4).
NUMBER	(number collected): calculated from monthly data on estimated number of fish of all species collected at all units (from Table 2, Column D, Total) and monthly data on percentage composition by species of the fish collected (from Table 4).
PERCENTO	(percent of the white perch collected that were young-of-the-year): calculated with the aid of graph paper and a dissecting microscope from the monthly plots in Fig. 10 of frequency versus length intervals of white perch collected at the Albany Steam Electric Generating Station for each month April through November 1974. The "DIVISION" criteria specified by Texas Instruments were used as the cut-off length between young-of-the-year and yearling white perch (see Table A-10 in this appendix).

April 1975 - March 1976: Ref. (2)

RATE	(collection rate): <sup>1</sup> calculated from monthly data on average observed number of fish of all species collected per million gallons of intake flow at all units (from Table IVC-16) and monthly data on percentage composition by species of the fish collected (from Table IVC-14).
NUMBER	(number collected): calculated from the monthly collection rates (RATE) described immediately above and monthly values of average daily plant flow for all units in millions of gallons per day times the number of days in the particular month.

TABLE A-1 (continued)

PERCENTO (percent of the white perch collected that were young-of-the-year): calculated with the aid of graph paper and a dissecting microscope from the plots in Fig. IVC-6 of relative frequency versus length intervals of white perch collected at the Albany Steam Electric Generating Station for each month May through November 1975. The "DIVISION" criteria specified by Texas Instruments were used as the cut-off point between young-of-the-year and yearling white perch (see Table A-10 in this appendix).

RATE, NUMBER, and PERCENTO values were approximated as follows for each month during 1974 through 1977 for which estimates were not directly available from Refs. (1) and (2). These approximations were necessary in order to have a complete data set with which to estimate exploitation rates and the conditional rates of mortality due to impingement (see Section 4).

RATE and NUMBER: approximations for each month were calculated as the average of the two monthly estimates available from the period April 1974 through March 1976. These approximations were used for January-March 1974 and April 1976 - December 1977.

PERCENTO: for May through November approximations were calculated as just described for RATE and NUMBER. The approximation for November was also used for the months of December and January of all years. The April 1974 value (no estimate for April 1975 was available) was used as the approximation for April 1975, 1976, and 1977 and for the months of February and March of all years.

$$\text{RATEO} = \text{PERCENTO} \cdot \text{RATE}/100 \text{ and } \text{RATEI} = \text{RATE} - \text{RATEO}.$$

$$\text{NUMBERO} = \text{PERCENTO} \cdot \text{NUMBER}/100 \text{ and } \text{NUMBERI} = \text{NUMBER} - \text{NUMBERO}.$$

RATE, NUMBER, and PERCENTO are defined above. RATEO and RATEI are the collection rates for young-of-the-year and for yearling and older white perch, respectively. NUMBERO and NUMBERI are number collected for young-of-the-year and for yearling and older white perch, respectively.

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<sup>1</sup>All collection rates were converted from number of white perch collected per million gallons to number of white perch collected per million cubic meters by multiplying by 264.17 gallons per cubic meter. Collection rates were assumed to equal impingement mortality rates.

TABLE A-1 (continued)

PLANT=ALBANY								
YEAR	MONTH	RATE	NUMBER	PERCENTO	RATED	RATE1	NUMBER0	NUMBER1
1974	1	0.000	3.5	10.70	0.0000	0.330	0.37	3.1
1974	2	0.528	15.5	19.60	0.1036	0.425	3.04	12.5
1974	3	6.868	260.5	19.60	1.3462	5.522	51.36	209.4
1974	4	77.138	3923.0	19.60	15.1190	62.019	768.91	3154.1
1974	5	95.101	5518.0	35.50	33.7509	51.340	1958.99	3559.1
1974	6	133.934	7717.0	0.30	0.0000	133.934	0.00	7717.0
1974	7	211.072	12518.0	0.00	0.0000	211.072	0.33	12518.0
1974	8	105.932	5234.0	5.88	6.2288	99.703	370.09	5923.9
1974	9	178.051	9868.0	2.44	4.3444	173.706	240.79	9627.2
1974	10	305.391	17325.0	1.79	5.4663	299.914	310.12	17014.9
1974	11	61.023	3516.0	9.43	5.7545	55.259	331.56	3184.4
1974	12	0.254	21.0	10.70	0.0283	0.236	2.25	18.9
1975	1	0.000	7.0	10.70	0.0000	0.330	0.75	6.3
1975	2	0.793	31.0	19.60	0.1553	0.637	6.00	24.9
1975	3	0.264	10.0	19.60	0.0518	0.212	1.96	8.0
1975	4	1.057	45.0	19.60	0.2071	0.850	8.82	36.2
1975	5	285.568	11717.0	6.58	18.7904	255.777	770.99	10946.0
1975	6	118.034	5583.0	0.30	0.0000	118.084	0.00	5583.0
1975	7	212.921	8336.0	0.00	0.0000	212.921	0.33	8336.0
1975	8	29.951	1457.0	6.12	1.8269	28.024	89.78	1377.2
1975	9	299.833	14714.0	12.40	37.1793	252.554	1824.54	12889.5
1975	10	133.406	5036.0	7.52	10.0321	123.374	453.91	5502.1
1975	11	69.213	2906.0	11.90	8.2363	50.976	345.81	2560.2
1975	12	0.254	15.0	10.70	0.0283	0.236	1.71	14.3
1976	1	0.000	0.0	10.70	0.0000	0.330	0.33	0.0
1976	2	0.300	3.0	19.60	0.0000	0.000	0.00	0.0
1976	3	13.208	511.0	19.60	2.5889	10.520	100.15	410.8
1976	4	39.097	1994.0	19.60	7.6630	31.434	388.86	1595.1
1976	5	190.202	8617.5	21.00	39.9425	150.250	1809.63	6807.8
1976	6	126.009	3026.5	0.30	0.0000	126.009	0.00	8026.5
1976	7	211.864	10427.0	0.00	0.0000	211.864	0.33	10427.0
1976	8	67.892	3330.5	6.00	4.0735	63.818	232.83	3647.7
1976	9	238.810	12291.0	7.42	17.7197	221.090	911.99	11379.0
1976	10	219.261	11580.5	4.66	10.2176	209.044	544.31	11136.2
1976	11	64.986	3211.0	10.70	6.9535	59.332	343.58	2867.4
1976	12	0.254	18.5	10.70	0.0283	0.236	1.98	16.5
1977	1	0.000	3.5	10.70	0.0000	0.330	0.37	3.1
1977	2	0.528	15.5	19.60	0.1036	0.425	3.04	12.5
1977	3	6.868	260.5	19.60	1.3462	5.522	51.36	209.4
1977	4	39.097	1994.0	19.60	7.6630	31.434	388.86	1595.1
1977	5	190.202	8617.5	21.00	39.9425	150.250	1809.63	6807.8
1977	6	126.009	3026.5	0.30	0.0000	126.009	0.00	8026.5
1977	7	211.864	10427.0	0.00	0.0000	211.864	0.33	10427.0
1977	8	67.892	3330.5	6.00	4.0735	63.818	232.83	3647.7
1977	9	238.810	12291.0	7.42	17.7197	221.090	911.99	11379.0
1977	10	219.261	11580.5	4.66	10.2176	209.044	544.31	11136.2
1977	11	64.986	3211.0	10.70	6.9535	59.332	343.58	2867.4
1977	12	0.254	18.5	10.70	0.0283	0.236	1.98	16.5

REFERENCES FOR TABLE A-1

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TABLE A-2

WHITE PERCH IMPINGEMENT DATA  
FOR THE ASTORIA GENERATING STATION (Ref. 1)

RATE	(collection rate): <sup>1</sup> calculated from monthly data on observed number of fish and crustaceans of all species collected per million gallons of intake flow at Units 1-5 (from Table 12) and monthly data on the percent of the total number of fish and crustaceans collected that were white perch (calculated from data in Table 4).
NUMBER	(number collected): calculated from the collection rate (RATE) described immediately above and the value for full flow through Units 1-6 in gallons per minute (from Table 1) times the number of minutes in the particular month.

Data with which to calculate RATE and NUMBER values were available only for the period January 1972 - December 1972. No data were available from which to estimate PERCENTO, the percent of the white perch collected at Astoria that were young-of-the-year. The white perch impingement data for Astoria have been used only in Section 2.B on seasonal variations in collection rates among the different power plants.

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<sup>1</sup>All collection rates were converted from number of white perch collected per million gallons to number of white perch collected per million cubic meters by multiplying by 264.17 gallons per cubic meter. Collection rates were assumed to equal impingement mortality rates.

TABLE A-2 (continued)

----- PLANT=ASTORIA -----								
YEAR	MONTH	RATE	NUMBER	PERCENTO	RATEO	RATE1	NUMBERO	NUMBER1
1972	1	1.04611	251	.	.	.	.	.
1972	2	4.62297	1041	.	.	.	.	.
1972	3	1.60087	339	.	.	.	.	.
1972	4	3.13570	757	.	.	.	.	.
1972	5	2.09223	522	.	.	.	.	.
1972	6	0.84534	204	.	.	.	.	.
1972	7	0.97440	213	.	.	.	.	.
1972	8	0.00000	0	.	.	.	.	.
1972	9	0.00000	0	.	.	.	.	.
1972	10	0.00000	0	.	.	.	.	.
1972	11	0.00000	0	.	.	.	.	.
1972	12	6.94767	1733	.	.	.	.	.

REFERENCE FOR TABLE A-2

1. Quirk, Lawler and Matusky Engineers. A Study of Impinged Organisms at the Astoria Generating Station. QL&M Project No. 115-16, prepared for Consolidated Edison Company of New York, Inc., September 1973.

TABLE A-3

WHITE PERCH IMPINGEMENT DATA FOR THE  
BOWLINE POINT GENERATING STATION

January 1973 - December 1976: Ref. (1)

Values for RATE (collection rate)<sup>1</sup> and NUMBER (number collected) were taken directly from data sheets in Ref. (1).

January 1977 - December 1977: Ref. (2)

Values for RATE (collection rate)<sup>1</sup> and NUMBER (number collected) were taken directly from data sheets in Ref. (2).

PERCENTO (percent of the white perch collected that were young-of-the-year):

January 1975 - December 1976: Calculated from monthly data on length-frequency in 1-centimeter length intervals of white perch in impingement collections [from Tables 10.2-13 and 10.2-14 in Ref. (3)]. The "DIVISION" criteria specified by Texas Instruments were used as the cut-off length between young-of-the-year and yearling white perch (see Table A-10 in this appendix).

January 1973 - December 1974 and January 1977 - December 1977: in the absence of monthly values during these two periods, estimates were calculated as the average of the 1975 and 1976 PERCENTO values for each month.

$$\text{RATEO} = \text{PERCENTO} \cdot \text{RATE}/100 \text{ and } \text{RATE1} = \text{RATE} - \text{RATEO}.$$

$$\text{NUMBERO} = \text{PERCENTO} \cdot \text{NUMBER}/100 \text{ and } \text{NUMBER1} = \text{NUMBER} - \text{NUMBERO}.$$

RATE, NUMBER, and PERCENTO are defined above. RATEO and RATE1 are the collection rates for young-of-the-year and for yearling and older white perch, respectively. NUMBERO and NUMBER1 are number collected for young-of-the-year and for yearling and older white perch, respectively.

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<sup>1</sup>All collection rates were converted from number of white perch collected per million gallons to number of white perch collected per million cubic meters by multiplying by 264.17 gallons per cubic meter. Collection rates were assumed to equal impingement mortality rates.

TABLE A-3 (continued)

PLANT-BOWLINE								
YEAR	MONTH	RATE	NUMBER	PERCENTO	RATEO	RATE1	NUMBERO	NUMBER1
1973	1	296.13	17021	82.6	244.51	51.527	14059	2961.7
1973	2	353.99	15184	78.8	278.94	75.045	12753	3431.0
1973	3	288.74	4476	84.8	244.35	43.838	3795	680.4
1973	4	462.56	23333	84.8	392.25	70.309	20270	3633.3
1973	5	235.90	14739	69.0	162.77	73.133	10173	4569.1
1973	6	19.55	809	0.0	0.00	19.549	0	809.0
1973	7	13.74	692	44.8	6.15	7.583	313	382.0
1973	8	46.44	2724	78.2	35.53	9.905	2130	593.8
1973	9	4.76	285	81.6	3.98	0.875	233	52.4
1973	10	5.02	326	92.6	4.65	0.371	302	24.1
1973	11	9.51	500	96.0	9.13	0.383	480	20.0
1973	12	373.01	13360	98.3	366.67	6.343	17753	307.0
1974	1	1092.87	58425	82.6	802.71	133.150	48259	10166.0
1974	2	1219.94	47003	78.8	961.31	258.627	37042	9965.7
1974	3	968.98	51689	84.8	821.59	147.294	43832	7856.7
1974	4	922.48	55907	84.8	782.26	140.217	48257	8649.9
1974	5	91.40	2901	69.0	63.07	28.335	2002	899.3
1974	6	19.49	1423	0.0	0.00	18.492	0	1423.0
1974	7	5.28	533	48.8	2.37	2.916	239	294.2
1974	8	3.43	372	78.2	2.69	0.749	291	81.1
1974	9	4.49	529	81.6	3.66	0.825	432	97.3
1974	10	29.32	3697	92.6	27.15	2.170	3423	273.6
1974	11	497.17	43360	96.0	477.28	19.897	41626	1734.8
1974	12	845.08	33095	98.3	830.71	14.366	88563	1531.6
1975	1	1898.59	176382	69.4	1317.62	580.968	122409	53972.9
1975	2	97.21	7354	68.0	66.11	31.109	5001	2353.3
1975	3	303.00	24651	71.8	217.56	85.447	17699	6951.6
1975	4	1350.70	113539	72.2	975.21	375.495	81953	31555.5
1975	5	173.82	9488	38.1	66.23	107.597	3615	5873.1
1975	6	15.06	1228	0.0	0.00	15.058	0	1228.0
1975	7	19.28	1809	89.5	17.26	2.025	1619	189.9
1975	8	4.23	445	66.7	2.82	1.407	297	148.5
1975	9	1.85	190	75.0	1.39	0.452	143	47.5
1975	10	2.34	133	85.2	2.03	0.352	113	19.7
1975	11	20.34	1351	96.5	19.63	0.7119	1014	36.79
1975	12	622.38	54906	99.1	616.78	5.5015	54412	494.15
1976	1	61.55	2936	95.7	58.90	2.6467	2810	126.25
1976	2	94.94	3335	89.7	85.07	9.7682	3413	391.92
1976	3	261.00	13906	97.7	255.00	6.0030	13586	319.88
1976	4	687.90	57131	97.5	670.70	17.1975	55703	1428.28
1976	5	22.98	1996	100.0	22.98	0.0000	1996	0.00
1976	6	9.25	912	0.0	0.00	9.2459	0	812.00
1976	7	2.91	308	0.0	0.00	2.9059	0	308.00
1976	8	113.86	13378	89.7	102.13	11.7273	9758	1120.43
1976	9	15.32	1512	88.2	13.51	1.8093	1334	178.42
1976	10	1.06	49	100.0	1.06	0.0000	49	0.00
1976	11	610.50	32966	95.4	582.41	28.0829	31451	1516.44
1976	12	1711.03	143371	97.5	1668.25	42.7757	145637	3734.28
1977	1	295.29	25081	82.6	243.91	51.3833	20717	4364.09
1977	2	306.57	24051	78.8	241.58	64.9927	18952	5098.81
1977	3	147.91	12697	84.8	125.43	22.4821	10767	1929.94
1977	4	81.73	7063	84.8	69.31	12.4236	5994	1074.34
1977	5	91.35	8520	69.0	63.03	28.3135	5879	2641.20
1977	6	24.57	1952	0.0	0.00	24.5678	0	1952.00
1977	7	5.26	338	44.8	2.36	2.9019	151	186.58
1977	8	66.36	7822	78.2	57.89	14.4664	6117	1705.20
1977	9	1.90	164	81.6	1.55	0.3530	134	30.18
1977	10	59.17	5122	92.6	54.80	4.3789	5669	853.03
1977	11	294.47	24756	96.0	282.69	11.7738	23765	990.24
1977	12	359.43	31356	98.3	353.32	6.1103	30528	527.95

REFERENCES FOR TABLE A-3

1. Letter dated March 3, 1978, from William J. Cahill, Jr. of Consolidated Edison Company of New York, Inc. (Con Ed) to Robert P. Geckler of the U. S. Nuclear Regulatory Commission (US NRC), including a response to Question X.1, which is the identification number for a question in Enclosure 2 of a letter dated July 26, 1977, from George W. Knighton (US NRC) to William Cahill, Jr. (Con Ed).
2. Letter dated May 5, 1978, from Edward G. Kelleher of Consolidated Edison Company of New York, Inc. (Con Ed) to Henry Gluckstern of the U. S. Environmental Protection Agency (US EPA), including a response to Question A-4, which is the identification number for a question in the enclosure of a letter dated March 23, 1978, from Henry Gluckstern (US EPA) to Kenneth L. Marcellus (Con Ed).
3. Ecological Analysts, Inc. Bowline Point Generating Station. Near-field Effects of Once-through Cooling System Operation on Hudson River Biota. Prepared for Orange and Rockland Utilities, Inc., July 1977 (Exhibit UT-7).

TABLE A-4

WHITE PERCH IMPINGEMENT DATA FOR  
THE DANSKAMMER POINT GENERATING STATION

RATE (collection rate):<sup>1</sup>

January 1972 - December 1976: average of the daily collection rates for each month were copied directly from data sheets in Ref. (1).

January 1977 - December 1977: average of the daily collection rates for each month were copied directly from data sheets in Ref. (2).

NUMBER (number collected):

January 1972 - December 1977: calculated from the monthly collection rates (RATE) described immediately above and monthly values of actual total plant intake flow in millions of gallons for the particular month, from data sheets in Ref. (3) for 1972 - 1976 and from data sheets provided by the U. S. Environmental Protection Agency, Region II, New York, New York for 1977.

PERCENTO (percent of the white perch collected that were young-of-the-year):

No estimates of PERCENTO were available for Danskammer. Consequently, all monthly values for PERCENTO were approximated based on data from Roseton, which is adjacent to Danskammer. (See Table A-9 in this appendix. Monthly PERCENTO values tabulated for Danskammer are exactly the same as those tabulated for Roseton for July 1973 - December 1977; monthly PERCENTO values for January 1972 - June 1973 were calculated as the average of the 1975 and 1976 Roseton values for each month.)

$$\text{RATEO} = \text{PERCENTO} \cdot \text{RATE}/100 \text{ and } \text{RATE1} = \text{RATE} - \text{RATEO}.$$

$$\text{NUMBERO} = \text{PERCENTO} \cdot \text{NUMBER}/100 \text{ and } \text{NUMBER1} = \text{NUMBER} - \text{NUMBERO}.$$

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<sup>1</sup>All collection rates were converted from number of white perch collected per million gallons to number of white perch collected per million cubic meters by multiplying by 264.17 gallons per cubic meter. Collection rates were assumed to equal impingement mortality rates.

RATE, NUMBER, and PERCENTO are defined above. RATEO and RATE1 are the collection rates for young-of-the-year and for yearling and older white perch, respectively. NUMBERO and NUMBER1 are number collected for young-of-the-year and for yearling and older white perch, respectively.

TABLE A-4 (continued)

PLANT=DANSKAM								
YEAR	MONTH	RATE	NUMBER	PERCENTO	RATEO	RATE1	NUMBERO	NUMBER1
1972	1	22.67	743	66.0	14.959	7.706	493.7	254.3
1972	2	11.23	318	53.0	5.950	5.277	168.5	149.5
1972	3	29.45	763	59.0	17.378	12.077	453.1	314.9
1972	4	137.32	4544	44.0	60.419	75.897	1999.4	2544.6
1972	5	744.57	23668	58.0	431.908	312.761	16627.4	12040.6
1972	6	546.04	23235	0.0	0.000	546.039	0.0	23235.0
1972	7	206.74	3696	4.8	9.923	196.816	465.4	9230.6
1972	8	253.34	12723	64.2	162.644	93.695	8168.2	4554.8
1972	9	172.82	7143	86.5	149.489	23.331	6178.7	964.3
1972	10	477.65	19732	88.6	423.194	54.452	17482.6	2249.4
1972	11	273.07	11398	85.3	232.931	40.142	9466.6	1631.4
1972	12	110.45	3775	73.8	81.512	28.939	2785.9	989.1
1973	1	9.09	291	66.0	5.998	3.090	185.5	95.5
1973	2	3.22	78	53.0	1.708	1.515	81.3	36.7
1973	3	24.22	719	59.0	14.292	9.932	424.2	294.8
1973	4	203.89	6959	44.0	89.710	114.176	3062.0	3897.0
1973	5	352.80	15344	58.0	204.623	148.176	8899.5	6444.5
1973	6	167.48	7931	0.0	0.000	167.484	0.0	7931.0
1973	7	485.17	25603	4.8	23.288	461.886	1229.2	24378.8
1973	8	88.76	4726	64.2	56.985	31.776	3334.1	1691.9
1973	9	171.21	8631	86.5	148.10	23.113	7465.9	1165.2
1973	10	505.41	21165	88.6	448.68	57.731	17866.2	2298.8
1973	11	451.36	17855	85.3	385.01	55.353	15230.3	2624.7
1973	12	77.24	2243	73.8	57.01	20.238	1659.0	589.0
1974	1	20.34	625	66.0	13.43	5.915	412.5	212.5
1974	2	1.29	37	53.0	0.69	0.608	19.6	17.4
1974	3	5.02	153	59.0	2.96	2.058	90.3	62.7
1974	4	668.35	19511	44.0	294.07	374.276	8584.8	10926.2
1974	5	393.96	15508	58.0	228.49	165.452	8994.6	6513.4
1974	6	381.57	12926	0.0	0.00	381.567	0.0	12926.0
1974	7	135.89	6273	4.8	6.52	129.355	301.1	5971.9
1974	8	119.96	5958	64.2	77.01	42.946	3825.0	2133.0
1974	9	53.18	2302	86.5	46.00	7.179	1991.2	310.8
1974	10	134.46	5577	88.6	119.13	15.329	5827.2	749.8
1974	11	137.74	5857	85.3	117.49	23.248	4996.0	861.0
1974	12	200.51	3525	73.8	147.97	52.532	6291.4	2233.6
1975	1	31.78	1006	59.9	19.04	12.744	502.5	403.4
1975	2	15.01	344	35.6	5.70	10.310	122.5	221.5
1975	3	15.93	224	38.5	6.13	9.797	86.2	137.8
1975	4	253.95	3935	7.0	17.78	236.170	275.4	3659.6
1975	5	139.98	3937	17.2	24.08	115.905	677.2	3259.8
1975	6	321.57	14827	0.0	0.00	321.574	0.0	14827.0
1975	7	103.45	4621	2.8	2.90	100.552	129.4	4491.6
1975	8	181.17	8999	39.7	71.92	109.244	3532.9	5366.1
1975	9	150.26	6861	77.7	116.75	33.538	5331.0	1530.0
1975	10	592.61	25015	79.7	472.31	120.300	19937.0	5078.0
1975	11	667.45	26385	76.2	508.60	158.854	20105.4	6279.6
1975	12	79.04	2175	66.0	52.17	26.873	1435.5	739.5
1976	1	43.35	1224	72.0	31.21	12.138	881.3	342.7
1976	2	32.76	766	70.4	23.06	9.696	539.3	226.7
1976	3	56.35	1440	79.6	44.85	11.495	1146.2	293.8
1976	4	1064.18	25709	81.0	861.99	202.195	20824.3	4884.7
1976	5	250.51	8845	98.7	247.26	3.257	8730.0	115.0
1976	6	232.81	3363	0.0	0.00	232.813	0.0	8363.0
1976	7	40.87	1387	6.9	2.82	38.047	95.7	1291.3
1976	8	25.05	972	88.8	23.13	2.917	863.1	108.9
1976	9	106.67	4719	95.3	101.66	5.014	4497.2	221.8
1976	10	553.73	19889	97.5	539.88	13.843	19390.8	497.2
1976	11	1329.25	39827	94.4	1254.81	74.438	37596.7	2230.3
1976	12	140.01	4588	81.5	114.11	25.902	3739.2	848.8
1977	1	21.71	668	66.0	14.33	7.333	440.9	227.1
1977	2	15.00	363	53.0	7.95	7.052	192.4	170.6
1977	3	152.08	4263	59.0	89.73	52.354	2515.2	1747.8
1977	4	1136.41	35174	44.0	500.02	636.388	15916.6	20257.4
1977	5	1205.75	48386	58.0	699.34	505.415	28363.9	20322.1
1977	6	227.74	5808	0.0	0.00	227.741	0.0	5808.0
1977	7	66.07	2725	4.8	3.17	62.899	130.8	2594.2
1977	8	125.01	5329	64.2	80.25	44.752	3421.2	1907.8
1977	9	117.24	4408	86.5	101.41	15.827	3812.9	595.1
1977	10	535.58	13026	88.6	474.52	61.056	15971.0	2055.0
1977	11	467.00	13191	85.3	398.35	68.649	11251.9	1939.1
1977	12	51.96	1490	73.8	38.35	13.614	1099.6	390.4

## REFERENCES FOR TABLE A-4

1. Letter dated March 3, 1978, from William J. Cahill, Jr. of Consolidated Edison Company of New York, Inc. (Con Ed) to Robert P. Geckler of the U. S. Nuclear Regulatory Commission (US NRC), including a response to Question IX.1, which is the identification number for a question in Enclosure 2 of a letter dated July 26, 1977, from George W. Knighton (US NRC) to William Cahill, Jr. (Con Ed).
2. Letter dated April 14, 1978, from Kenneth L. Marcellus of Consolidated Edison Company of New York, Inc. (Con Ed) to Henry Gluckstern of the U. S. Environmental Protection Agency (US EPA), including a response to Question A-5, which is the identification number for a question in the enclosure of a letter dated March 23, 1978, from Henry Gluckstern (US EPA) to Kenneth L. Marcellus (Con Ed).
3. Letter dated October 31, 1977, from Kenneth L. Marcellus of Consolidated Edison Company of New York, Inc. to Henry Gluckstern of the U. S. Environmental Protection Agency, including in Attachment 2 a response to Question 7 (9/27/77) of Attachment C which accompanied the October 12, 1977 EPA "Motion to Specify Area of Requestors' Testimony To Be Cross-Examined During Initial Phase of Hearing."

TABLES A-5, A-6, A-7

WHITE PERCH IMPINGEMENT DATA FOR  
INDIAN POINT UNITS 1, 2, AND 3

RATE (collection rate):<sup>1</sup>

June 1972 - December 1975: Copied directly from data sheets provided in Ref. (1).

January 1976 - December 1977: Copied directly from data sheets provided in Ref. (2).

NUMBER (number collected):

May 1972 - December 1976: Copied directly from appendix tables in Refs. (3) - (6). However, if a NUMBER value in these Texas Instruments (TI) appendix tables was lower than the corresponding NUMBER value in Refs. (1) and (2), then the updated NUMBER value in Refs. (1) and (2) was used. For example, such substitutions were made for Indian Point Unit 2 (Table A-6 in this appendix) for all months of 1973. In general, the NUMBER values presented in the TI appendix tables are the same as or higher than the NUMBER values presented in Refs. (1) and (2), for the reason discussed by Con Edison in their response to Question VI.2 in Ref. 1. Thus, the substituted, higher values from Refs. (1) and (2) can still be low, because they were selected by TI to include only data that represented known flow volumes and associated impingement collections.

January 1977 - December 1977: Copied directly from data sheets provided in Refs. (7) and (8).

PERCENTO (percent of the white perch collected that were young-of-the-year):

June 1975 - December 1976: Calculated from data on magnetic tapes provided by Consolidated Edison. The two tapes used were Texas Instruments 1975 Impingement Data (Record Type D) and Texas Instruments 1976 Impingement Data (Record Type D). Monthly estimates of PERCENTO were calculated for each unit for which there were white perch impingement data as follows:

$$\text{PERCENTO} = \frac{\text{Number of impinged white perch in Length Class 1}}{\text{Total number of impinged white perch}} \cdot 100 ,$$

where the bounds on Length Class 1 are 0 mm to DIVISION, where DIVISION is the seasonally-varying, total body length in millimeters which is used as the cut-off length between young-of-the-year and yearling white perch (see Table A-10 of this appendix).

$$\text{RATEO} = \text{PERCENTO} \cdot \text{RATE}/100 \text{ and } \text{RATE1} = \text{RATE} - \text{RATEO}.$$

$$\text{NUMBERO} = \text{PERCENTO} \cdot \text{NUMBER}/100 \text{ and } \text{NUMBER1} = \text{NUMBER} - \text{NUMBERO}.$$

RATE, NUMBER, and PERCENTO are defined above. RATEO and RATE1 are the collection rates for young-of-the-year and for yearling and older white perch, respectively. NUMBERO and NUMBER1 are number collected for young-of-the-year and for yearling and older white perch, respectively.

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<sup>1</sup>All RATE values are given in the original sources in units of number of white perch collected per million cubic meters, and thus multiplication by 264.17 was not necessary.

Collection rates were not assumed to equal impingement mortality rates. Rather, the collection rates were adjusted upward to account for the calculated efficiencies of less than 100%. For Units 1 and 2, RATE = RATE/0.15 (i.e., 15% efficiency) and for Unit 3, RATE = RATE/0.70 (i.e., 70% efficiency). These efficiency estimates are based on data presented in Ref. (9) for Units 2 and 3; Unit 1 was assumed to have the same collection efficiency as Unit 2, since Units 1 and 2 have similar intake structures.

TABLE A-5 (continued)

PLANT-IP1								
YEAR	MONTH	RATE	NUMBER	PERCENTO	RATE0	RATE1	NUMBR00	NUMBR1
1972	5	.	1927	94.4	.	.	1819	107.9
1972	6	65.80	11320	0.0	0.00	65.800	0	11320.0
1972	7	52.40	2127	45.1	23.63	28.768	959	1167.5
1972	8	232.93	10560	84.8	197.53	35.406	8955	1605.1
1972	9	380.07	12087	84.5	321.16	58.910	10213	1873.4
1972	10	2236.00	84607	94.0	2101.84	134.150	79530	5076.4
1972	11	1705.60	35933	96.7	1649.32	56.285	34748	1185.8
1972	12	844.20	17420	96.4	813.81	33.391	16793	627.1
1973	1	62.40	7933	94.0	58.66	3.744	7457	476.0
1973	2	.	64540	97.3	.	.	62797	1742.6
1973	3	.	205400	91.1	.	.	188030	18369.6
1973	4	.	163253	97.8	.	.	159662	3591.6
1973	5	885.50	23533	94.4	836.01	49.594	19478	1155.5
1973	6	186.27	4527	0.0	0.00	185.257	0	4526.7
1973	7	.	2540	45.1	.	.	1146	1394.5
1973	8	11.53	15367	84.8	9.78	1.753	13031	2335.7
1973	9	.	1460	84.5	.	.	1234	226.3
1973	10	.	287	94.0	.	.	269	17.2
1973	11	.	4273	96.7	.	.	4132	141.0
1973	12	.	12187	96.4	.	.	11748	438.7
1974	1	3798.07	32107	94.0	3570.18	227.884	30180	1926.4
1974	2	1661.33	44567	97.3	1616.48	44.856	43363	1203.3
1974	3	1680.33	43213	91.1	1530.78	149.550	39367	3846.0
1974	4	1826.13	56220	97.8	1785.96	40.175	54983	1236.8
1974	5	594.67	15690	94.4	561.37	33.301	14802	878.1
1974	6	161.20	7647	0.0	0.00	161.200	0	7646.7
1974	7	35.73	1573	45.1	16.12	19.618	710	863.8
1974	8	22.60	1140	84.8	19.16	3.435	967	173.3
1974	9	60.20	2973	84.5	50.87	9.331	2512	460.9
1974	10	631.87	30227	94.0	593.95	37.912	28413	1813.6
1974	11	895.00	15733	96.7	866.43	29.568	15214	519.2
1974	12	6241.47	143867	96.4	6016.77	224.593	138687	5179.2
1975	1	4255.13	62007	94.0	3999.83	255.308	58286	3720.4
1975	2	6964.67	102447	97.3	6776.62	198.046	99681	2766.1
1975	3	2460.07	39213	91.1	2241.12	218.946	35723	3490.0
1975	4	4757.20	74073	97.8	4652.54	104.658	72444	1629.6
1975	5	471.73	5180	94.4	445.32	26.417	4890	290.1
1975	6	58.27	827	0.0	0.00	58.257	0	826.7
1975	7	63.87	407	66.0	42.15	21.715	268	138.3
1975	8	63.13	287	90.9	57.39	5.745	261	26.1

TABLE A-6 (continued)

----- PLANT=IP2 -----

YEAR	MONTH	RATE	NUMBER	PERCENTO	RATEO	RATE1	NUMBERO	NUMBER1
1972	6	42.4	960	0.0	0.0	42.40	J	960
1972	9	34.3	1347	84.5	29.0	5.31	1138	209
1972	10	135.1	1687	94.0	127.0	8.11	1585	101
1973	1	3863.1	7933	94.0	3636.0	232.09	7457	476
1973	2	4578.3	63693	97.3	4454.7	123.62	61974	1720
1973	3	4280.1	201547	91.1	3899.2	380.93	183609	17938
1973	4	4696.1	117680	97.8	4592.8	103.31	115091	2589
1973	5	1136.1	20560	94.4	1072.4	63.62	19409	1151
1973	6	97.9	4527	0.0	0.0	97.93	J	4527
1973	7	38.6	2540	45.1	17.4	21.19	1146	1394
1973	8	187.0	15180	84.8	158.6	28.42	12873	2307
1973	9	31.3	1453	84.5	26.4	4.85	1228	225
1973	10	5.3	287	94.0	5.0	0.32	259	17
1973	11	273.3	4200	96.7	264.3	9.02	4061	139
1973	12	1264.1	12187	96.4	1218.6	45.51	11749	439
1974	1	12814.7	147813	94.0	12045.8	768.88	138945	8869
1974	2	12823.3	153027	97.3	12477.1	345.23	148895	4132
1974	3	9218.7	259980	91.1	8398.2	820.46	236842	23138
1974	4	8378.7	471647	97.8	8194.3	184.33	461270	10376
1974	5	4351.4	395840	94.4	4107.7	243.68	373673	22167
1974	6	420.5	49560	0.0	0.0	420.53	J	49560
1974	7	42.3	4753	45.1	19.1	23.24	2144	2610
1974	8	69.7	8160	84.8	59.1	10.60	6920	1240
1974	9	206.0	23360	84.5	174.1	31.93	19739	3621
1974	10	805.3	75780	94.0	757.0	48.32	71233	4547
1974	11	1897.3	165967	96.7	1825.1	62.28	161457	5510
1974	12	6787.3	370153	96.4	6543.0	244.34	356828	13326
1975	1	4416.0	212397	94.0	4151.0	264.96	199643	12743
1975	2	3496.1	165833	97.3	3401.7	94.40	161356	4478
1975	3	3171.2	33973	91.1	2889.0	282.24	81966	8008
1975	4	5900.1	451100	97.8	5770.3	129.80	441176	9924
1975	5	807.0	33373	94.4	761.8	45.19	78704	4669
1975	6	90.5	12207	0.0	0.0	90.47	J	12207
1975	7	92.7	11713	56.4	52.3	40.40	6606	5107
1975	8	1030.1	89720	98.5	1014.7	15.45	88374	1346
1975	9	640.0	73693	95.0	608.0	32.00	70009	3685
1975	10	657.5	47720	95.8	629.9	27.61	45716	2004
1975	11	1729.9	179340	95.2	1645.9	82.99	170732	8608
1975	12	2847.1	294000	97.9	2787.3	59.79	287826	6174
1976	1	9597.3	610240	94.0	9021.5	575.84	573626	36614
1976	2	3731.8	180087	95.6	3567.6	154.20	172163	7924
1976	3	1563.0	123027	91.1	1423.9	139.11	112077	10949
1976	4	245.0	287	97.7	239.4	5.64	280	7
1976	6	36.9	493	0.0	0.0	36.93	0	493
1976	9	290.3	8227	90.7	263.3	27.00	7462	765
1976	10	2332.7	256390	95.4	2225.4	107.30	244587	11793
1976	11	1432.5	20900	98.3	1408.1	24.35	20545	355
1976	12	22551.3	590520	94.1	21220.8	1330.53	649779	40741
1977	1	36380.7	2164740	94.0	34197.8	2192.94	2034856	129884
1977	2	68453.3	1251787	97.3	66605.1	1848.24	1227718	34068
1977	3	5005.5	458480	91.1	4560.0	445.49	417675	40805
1977	4	10549.3	237347	97.8	10317.2	232.09	232125	5222
1977	5	339.73	25053	94.4	320.71	19.025	24594	1459.0
1977	6	299.87	37567	0.0	0.00	299.857	J	37566.7
1977	7	104.47	947	45.1	47.11	57.352	427	519.7
1977	8	463.07	43460	84.8	392.68	70.335	36854	6605.9
1977	9	146.87	22320	84.5	124.10	22.764	19367	3552.6
1977	10	2064.00	322480	94.0	1940.16	123.840	303131	19348.8
1977	11	9770.67	933973	96.7	9448.23	322.432	908954	31019.1
1977	12	.	543540	96.4	.	.	523973	19567.4

TABLE A-7 (continued)

----- PLANT=IP3 -----

YEAR	MONTH	RATE	NUMBER	PERCENTO	RATE0	RATE1	NUMBER0	NUMBER1
1974	3	38.93	6	91.1	35.46	3.455	5	0.5
1974	4	999.84	4371	97.8	977.85	21.997	4275	96.2
1974	5	458.90	677	94.4	433.20	25.698	639	37.9
1974	6	84.73	1430	0.0	0.00	84.729	0	1430.0
1974	7	5.71	20	45.1	2.58	3.137	9	11.0
1974	8	0.53	3	84.8	0.53	0.096	2	0.4
1974	9	2.20	13	84.5	1.86	0.341	11	2.0
1974	10	19.13	90	94.0	17.98	1.148	85	5.4
1976	2	446.86	3974	99.0	442.39	4.459	3935	39.7
1976	4	333.39	4554	97.8	326.05	7.334	4454	100.2
1976	5	105.57	7373	94.4	99.56	5.912	6963	412.9
1976	6	26.51	2254	0.0	0.00	26.514	0	2254.3
1976	7	16.81	1509	13.0	2.19	14.528	196	1312.5
1976	8	45.43	4170	64.9	29.48	15.945	2706	1463.7
1976	9	39.27	3199	67.8	26.53	12.645	2169	1029.9
1976	10	221.57	21865	90.9	201.41	20.163	19876	1989.8
1976	11	1332.03	118493	96.6	1286.74	45.239	114464	4028.8
1976	12	819.24	56426	97.2	796.30	22.939	54846	1579.9
1977	1	1953.43	92889	94.0	1836.22	117.206	37315	5573.3
1977	2	5655.71	127396	97.3	5503.98	152.731	123956	3439.7
1977	3	352.47	29314	91.1	321.10	31.370	26705	2609.0
1977	4	559.00	35919	97.8	546.70	12.298	55569	1250.0
1977	5	346.41	62640	94.4	327.02	19.399	59132	3507.8
1977	6	84.86	11370	0.0	0.00	84.857	0	11370.0
1977	7	32.23	4756	45.1	14.54	17.633	2145	2610.9
1977	8	94.06	13193	84.8	79.76	14.297	11179	2003.8
1977	9	40.06	5931	84.5	33.85	5.209	5012	919.4
1977	10	119.64	4013	94.0	112.46	7.179	3769	240.6
1977	12	514.26	18124	96.4	495.74	19.513	17472	652.5

## REFERENCES FOR TABLES A-5, A-6, AND A-7

1. Letter dated March 3, 1978, from William J. Cahill, Jr. of Consolidated Edison Company of New York, Inc. (Con Ed) to Robert P. Geckler of the U. S. Nuclear Regulatory Commission (US NRC), including a response to Question VI.3, which is the identification number for a question in Enclosure 2 of a letter dated July 26, 1977, from George W. Knighton (US NRC) to William Cahill, Jr. (Con Ed).
2. Letter dated May 3, 1978, from Kenneth L. Marcellus of Consolidated Edison Company of New York, Inc. (Con Ed) to Henry Gluckstern of the U. S. Environmental Protection Agency (US EPA), including a response to Question A-3, which is the identification number for a question in the enclosure of a letter dated March 23, 1978, from Henry Gluckstern (US EPA) to Kenneth L. Marcellus (Con Ed).
3. Texas Instruments, Inc. Indian Point Impingement Study Report for the Period 15 June 1972 through 31 December 1973. Prepared for Consolidated Edison Company of New York, Inc., December 1974. (Tables A-1.5 through A-1.8).
4. Texas Instruments, Inc. Indian Point Impingement Study Report for the Period 1 January 1974 through 31 December 1974. Prepared for Consolidated Edison Company of New York, Inc., November 1975. (Tables B-2 through B-4).
5. Texas Instruments, Inc. Indian Point Impingement Study Report for the Period 1 January 1975 through 31 December 1975. Prepared for Consolidated Edison Company of New York, Inc., November 1976. (Tables A-4 and A-5).
6. Texas Instruments, Inc. Hudson River Ecological Study in the Area of Indian Point. 1976 Annual Report. Prepared for Consolidated Edison Company of New York, Inc., December 1977. (Tables A-2 and A-3).
7. Monthly letters from Eugene R. McGrath of Consolidated Edison Company of New York, Inc. to Peter A. A. Berle of the New York State Department of Environmental Conservation, which are sent as specified in Section 401 Certification and which include data sheets giving daily fish counts by species for each unit at Indian Point.
8. Monthly letters from William J. Cahill, Jr. of Consolidated Edison Company of New York, Inc. to James P. O'Reilly of the U. S. Nuclear Regulatory Commission, which are sent as specified in Appendix B of Unit Nos. 1, 2 and 3 Technical Specifications and which include data sheets giving daily fish counts by species for each unit at Indian Point.

9. Exhibit UT-105. Table 1. Summary of Collection Efficiency Tests and Related 95% Confidence Intervals at Indian Point Units 2 and 3, 1974-1977. U. S. Environmental Protection Agency, Region II, Adjudicatory Hearing, Docket No. C/II-WP-77-01, introduced into evidence on June 6, 1978.

TABLE A-8

WHITE PERCH IMPINGEMENT DATA FOR THE  
LOVETT GENERATING STATION

January 1973 - December 1976: Ref. (1)

Values for RATE (collection rate)<sup>1</sup> and NUMBER (number collected) were taken directly from data sheets in Ref. (1).

January 1977 - December 1977: Ref. (2)

Values for RATE (collection rate)<sup>1</sup> and NUMBER (number collected) were taken directly from data sheets in Ref. (2).

PERCENTO (percent of the white perch collected that were young-of-the-year):

No estimates of PERCENTO were available for Lovett. Consequently, all monthly values for PERCENTO were approximated based on data from Indian Point, which is located only 1½ miles upriver and across the river from Lovett.

June 1975 - December 1976

Used the average of the observed monthly values for the units at Indian Point for the corresponding month and year (see Tables A-5 to A-7 in this appendix).

January 1973 - May 1975 and January 1977 - December 1977

Used the monthly approximations calculated for Indian Point (same for all units at Indian Point) (see Tables A-5 to A-7 in this appendix).

$$\text{RATEO} = \text{PERCENTO} \cdot \text{RATE}/100 \text{ and } \text{RATE1} = \text{RATE} - \text{RATEO}.$$

$$\text{NUMBERO} = \text{PERCENTO} \cdot \text{NUMBER}/100 \text{ and } \text{NUMBER1} = \text{NUMBER} - \text{NUMBERO}.$$

RATE, NUMBER, and PERCENTO are defined above. RATEO and RATE1 are the collection rates for young-of-the-year and for yearling and older white perch, respectively. NUMBERO and NUMBER1 are number collected for young-of-the-year and for yearling and older white perch, respectively.

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<sup>1</sup>All collection rates were converted from number of white perch collected per million gallons to number of white perch collected per million cubic meters by multiplying by 264.17 gallons per cubic meter. Collection rates were assumed to equal impingement mortality rates.

TABLE A-8 (continued)

----- PLANT=LOVETT -----								
YEAR	MONTH	RATE	NUMBER	PERCENTO	RATE0	RATE1	NUMBER0	NUMBER1
1973	1	70.80	3536	94.0	66.55	1.248	3323.8	212.16
1973	2	81.63	3585	97.3	79.42	2.204	3488.2	96.80
1973	3	222.43	11055	91.1	202.63	19.796	10071.1	983.90
1973	4	196.54	3569	97.8	192.22	4.324	8380.5	188.52
1973	5	66.04	2703	94.4	62.34	3.638	2551.6	151.37
1973	6	49.40	2247	0.0	0.00	49.400	0.0	2247.00
1973	7	16.38	817	45.1	7.39	3.932	368.5	448.53
1973	8	85.86	4417	84.8	72.81	13.050	3745.6	671.38
1973	9	13.74	600	84.5	11.61	2.123	507.0	93.00
1973	10	2.64	93	94.0	2.48	0.159	87.4	5.58
1973	11	142.12	6037	96.7	137.43	4.690	5837.8	199.22
1973	12	389.65	17292	96.4	375.62	14.027	16669.5	622.51
1974	1	458.33	20058	94.0	430.83	27.530	18954.5	1203.48
1974	2	399.16	12695	97.3	388.38	10.777	12352.2	342.77
1974	4	522.26	18835	97.8	510.77	11.430	18420.6	414.37
1974	5	163.26	5243	94.4	154.11	9.142	5893.4	349.61
1974	6	40.68	1519	0.0	0.00	40.682	0.0	1519.00
1974	7	8.98	184	45.1	4.05	4.931	83.0	101.02
1974	8	12.15	492	84.8	10.30	1.837	417.2	74.78
1974	9	10.57	396	84.5	8.93	1.638	334.6	61.38
1974	10	108.84	2921	94.0	102.31	5.533	2745.7	175.26
1974	11	302.74	11753	96.7	292.75	9.990	11365.2	387.85
1974	12	311.72	12071	96.4	300.50	11.222	11636.4	434.56
1975	1	850.36	35169	94.0	799.34	51.022	33998.9	2170.14
1975	2	121.52	4325	97.3	118.24	3.231	4208.2	116.78
1975	3	163.80	4249	91.1	153.78	15.024	3870.8	378.16
1975	4	546.30	11864	97.8	534.28	12.019	11503.0	261.01
1975	5	25.15	786	94.4	24.69	1.465	742.0	44.02
1975	6	26.68	958	0.0	0.00	26.681	0.0	958.00
1975	7	7.40	273	61.2	4.53	2.870	167.1	105.92
1975	8	42.80	1642	94.7	40.53	2.258	1555.0	87.03
1975	9	24.30	642	95.0	23.09	1.215	609.9	32.10
1975	10	30.38	977	95.8	29.10	1.276	936.0	41.03
1975	11	540.49	15522	95.2	514.55	25.944	15824.1	797.86
1975	12	143.97	4458	97.9	140.95	3.023	4364.4	93.62
1976	1	362.71	11376	94.0	340.94	21.762	11163.4	712.56
1976	2	42.27	1265	97.3	41.13	1.141	1230.8	34.16
1976	3	94.04	2592	91.1	85.67	8.370	2452.4	239.59
1976	4	186.50	4765	97.8	182.40	4.103	4660.2	104.83
1976	5	8.19	90	94.4	7.73	0.459	85.0	5.04
1976	6	26.68	610	0.0	0.00	26.681	0.0	610.00
1976	7	10.30	221	13.0	1.34	8.963	28.7	192.27
1976	8	17.70	554	64.9	11.49	5.212	359.5	194.45
1976	9	22.19	514	79.2	17.57	4.616	407.1	106.91
1976	10	12.42	167	93.2	11.57	0.944	155.6	11.36
1976	11	570.08	10200	97.4	555.26	14.822	9934.8	265.20
1976	12	534.94	13166	95.6	511.41	23.538	12586.7	579.30
1977	1	1225.33	39699	94.0	1152.28	73.550	37307.7	2381.34
1977	2	751.96	13633	97.3	731.66	20.303	13264.9	368.09
1977	3	106.46	1719	91.1	96.99	9.475	1566.0	152.99
1977	4	162.62	2783	97.8	159.05	3.578	2721.3	61.23
1977	5	21.24	370	94.4	20.05	1.189	349.3	20.72
1977	6	209.355	4732	0.0	0.000	209.355	0.00	4732.00
1977	7	19.179	576	45.1	8.650	10.529	259.78	316.22
1977	8	37.433	1408	84.8	31.743	5.690	1193.98	214.02
1977	9	4.755	121	84.5	4.018	0.737	102.24	19.76
1977	10	227.847	5519	94.0	214.176	13.671	5187.86	331.14
1977	11	490.405	9767	96.7	474.222	15.183	9444.69	322.31
1977	12	42.716	569	96.4	41.179	1.538	643.95	24.05

REFERENCES FOR TABLE A-8

1. Letter dated March 3, 1978, from William J. Cahill, Jr. of Consolidated Edison Company of New York, Inc. (Con Ed) to Robert P. Geckler of the U. S. Nuclear Regulatory Commission (US NRC), including a response to Question X.1, which is the identification number for a question in Enclosure 2 of a letter dated July 26, 1977 from George W. Knighton (US NRC) to William Cahill, Jr. (Con Ed).
2. Letter dated May 5, 1978 from Edward G. Kelleher of Consolidated Edison Company of New York, Inc. (Con Ed) to Henry Gluckstern of the U. S. Environmental Protection Agency (US EPA), including a response to Question A-4, which is the identification number for a question in the enclosure of a letter dated March 23, 1978 from Henry Gluckstern (US EPA) to Kenneth L. Marcellus (Con Ed).

## TABLE A-9

WHITE PERCH IMPINGEMENT DATA FOR THE  
ROSETON GENERATING STATIONRATE (collection rate):<sup>1</sup>

July 1973 - December 1976: average of the daily collection rates for each month were copied directly from data sheets in Ref. (1).

January 1977 - December 1977: average of the daily collection rates for each month were copied directly from data sheets in Ref. (2).

## NUMBER (number collected):

July 1973 - December 1976: copied directly from Table 10.2-14 of Ref. (3).

January 1977 - December 1977: calculated from the monthly collection rates (RATE) described immediately above and monthly values of actual total plant intake flow in millions of gallons for the particular month (from data sheets provided by the U. S. Environmental Protection Agency, Region II, New York, New York).

## PERCENTO (percent of the white perch collected that were young-of-the-year):

January 1975 - December 1976: Calculated from monthly data on length-frequency in 1-centimeter length intervals of white perch in impingement collections [from Tables 10.2-15 and 10.2-16 in Ref. (3)]. The "DIVISION" criteria specified by Texas Instruments were used as the cut-off length between young-of-the-year and yearling white perch (see Table A-10 in this appendix).

July 1973 - December 1974 and January 1977 - December 1977: calculated as the average of the 1975 and 1976 PERCENTO values for each month.

$$\text{RATEO} = \text{PERCENTO} \cdot \text{RATE}/100 \text{ and } \text{RATE1} = \text{RATE} - \text{RATEO}.$$

$$\text{NUMBERO} = \text{PERCENTO} \cdot \text{NUMBER}/100 \text{ and } \text{NUMBER1} = \text{NUMBER} - \text{NUMBERO}.$$

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<sup>1</sup>All collection rates were converted from number of white perch collected per million gallons to number of white perch collected per million cubic meters by multiplying by 264.17 gallons per cubic meter. Collection rates were assumed to equal impingement mortality rates.

TABLE A-9 (continued)

RATE, NUMBER, and PERCENTO are defined above. RATEO and RATE1 are the collection rates for young-of-the-year and for yearling and older white perch, respectively. NUMBERO and NUMBER1 are number collected for young-of-the-year and for yearling and older white perch, respectively.

TABLE A-9 (continued)

----- PLANT=ROSETON -----								
YEAR	MONTH	RATE	NUMBER	PERCENTO	RATEO	RATE1	NUMBERO	NUMBER1
1973	7	9.272	31	4.8	0.445	8.827	3.9	77.1
1973	8	98.430	980	64.2	63.192	35.238	629.2	350.8
1973	9	428.008	1094	86.5	370.227	57.781	946.3	147.7
1973	10	654.270	4522	88.6	579.583	74.537	4006.5	515.5
1973	11	197.837	1996	85.3	168.755	29.082	1702.6	293.4
1973	12	27.527	484	73.8	20.315	7.212	357.2	126.8
1974	1	1.162	5	66.0	0.767	0.395	3.3	1.7
1974	2	0.000	0	53.0	0.000	0.000	0.0	0.0
1974	3	0.423	5	59.0	0.249	0.173	2.9	2.1
1974	4	148.701	4897	44.0	65.429	93.273	2154.7	2742.3
1974	5	413.637	5272	58.0	239.910	173.728	3637.8	2634.2
1974	6	106.566	1105	0.0	0.000	106.566	0.0	1105.0
1974	7	0.687	10	4.8	0.033	0.654	0.5	9.5
1974	8	54.023	3263	64.2	34.683	19.340	2094.8	1168.2
1974	9	23.617	1131	86.5	20.429	3.188	978.3	152.7
1974	10	43.007	1038	88.6	38.104	4.903	919.7	118.3
1974	11	188.829	12313	85.3	161.071	27.758	10503.0	1810.0
1974	12	104.030	7351	73.8	76.774	27.256	5425.0	1926.0
1975	1	18.228	1307	59.9	10.918	7.309	782.9	524.1
1975	2	14.318	1059	35.6	5.097	3.221	377.0	682.0
1975	3	14.926	1047	38.5	5.746	9.179	403.1	643.9
1975	4	340.092	23288	7.0	23.806	315.286	1630.2	21657.8
1975	5	164.314	14599	17.2	28.262	136.052	2511.0	12088.0
1975	6	19.707	1613	0.0	0.000	19.707	0.0	1613.0
1975	7	42.928	3965	2.8	1.202	41.726	108.2	3756.8
1975	8	128.413	9571	39.7	50.980	77.433	3799.7	5771.3
1975	9	118.348	7904	77.7	91.957	26.392	6063.7	1740.3
1975	10	442.960	33541	79.7	353.039	89.921	26732.2	6808.8
1975	11	615.727	40951	76.2	469.184	146.543	31128.5	9722.5
1975	12	21.107	844	66.0	13.931	7.176	557.0	287.0
1976	1	19.575	1008	72.0	14.094	5.481	725.8	282.2
1976	2	34.712	2287	70.4	24.437	10.275	1610.0	677.0
1976	3	17.779	1129	79.6	14.152	3.627	898.7	230.3
1976	4	463.513	31493	81.0	375.445	88.067	25509.3	5983.7
1976	5	242.719	20841	98.7	239.564	3.155	20570.1	270.9
1976	6	75.870	6455	0.0	0.000	75.870	0.0	6455.0
1976	7	3.408	326	6.9	0.235	3.173	22.5	303.5
1976	8	22.692	2100	88.8	20.151	2.542	1864.8	235.2
1976	9	28.927	2346	95.3	27.567	1.360	2235.7	110.3
1976	10	140.459	3927	97.5	136.948	3.511	9678.8	248.2
1976	11	563.316	23006	94.4	531.770	31.546	21717.7	1288.3
1976	12	63.876	3258	81.5	52.059	11.817	2655.3	602.7
1977	1	23.036	1696	66.0	15.204	7.832	1119.4	576.6
1977	2	13.314	851	53.0	7.057	6.258	451.0	400.0
1977	3	67.178	5183	59.0	39.635	27.543	3058.0	2125.0
1977	4	303.954	15486	44.0	133.740	170.214	7253.8	9232.2
1977	5	735.106	51444	58.0	426.361	309.744	29837.5	21606.5
1977	6	20.552	1364	0.0	0.000	20.552	0.0	1964.0
1977	7	10.620	1004	4.8	0.510	10.110	48.2	955.8
1977	8	248.346	25808	64.2	159.438	88.908	16568.7	9239.3
1977	9	78.247	7248	86.5	67.584	10.553	6269.5	978.5
1977	10	142.493	10176	88.6	126.249	16.244	9015.9	1160.1
1977	11	119.484	7834	85.3	101.920	17.564	5682.4	1151.6
1977	12	32.942	2296	73.8	24.311	8.631	1694.4	601.6

## REFERENCES FOR TABLE A-9

1. Letter dated March 3, 1978, from William J. Cahill, Jr. of Consolidated Edison Company of New York, Inc., (Con Ed) to Robert P. Geckler of the U. S. Nuclear Regulatory Commission (US NRC), including a response to Question IX.1, which is the identification number for a question in Enclosure 2 of a letter dated July 26, 1977, from George W. Knighton (US NRC) to William Cahill, Jr. (Con Ed).
2. Letter dated April 14, 1978, from Kenneth L. Marcellus of Consolidated Edison Company of New York, Inc. (Con Ed) to Henry Gluckstern of the U. S. Environmental Protection Agency (US EPA), including a response to Question A-5, which is the identification number for a question in the enclosure of a letter dated March 23, 1978, from Henry Gluckstern (US EPA) to Kenneth L. Marcellus (Con Ed).
3. Ecological Analysts, Inc. Roseton Generating Station. Near-field Effects of Once-through Cooling System Operation on Hudson River Biota. Prepared for Central Hudson Gas & Electric Corporation, July 1977.

TABLE A-10. "DIVISION" CRITERIA SPECIFIED BY TEXAS INSTRUMENTS AS THE CUT-OFF LENGTH BETWEEN YOUNG-OF-THE-YEAR AND YEARLING WHITE PERCH<sup>1</sup>

DATE <sup>2</sup>	DIVISION <sup>3</sup> (mm)	YEAR CLASSES <sup>4</sup>	DATE <sup>2</sup>	DIVISION <sup>3</sup> (mm)	YEAR CLASSES <sup>4</sup>	
750101	95	1973-1974	760105	105	1974-1975	
750101	95		760119	105		
750116	95		760202	105		
750116	95		760216	105		
750201	95		760301	105		
750201	95		760315	105		
750215	95		760405	105		
750215	95		760419	105		
750301	95		760419	105		
750301	95		760503	105		
750315	95		760517	105		
750315	95		760607	50		1975-1976
750401	95		760607	50		
750401	95		760621	50		
750415	95		760705	50		
750415	95		760719	60		
750501	95		760802	60		
750501	95		760816	85		
750515	95		760816	85		
750515	95	760830	100			
750601	29	1974-1975	760830	100		
750601	29		760913	100		
750615	50		760913	100		
750615	50		760927	100		
750701	50		760927	100		
750701	50		761011	100		
750715	60		761011	100		
750715	60		761025	100		
750805	85		761025	100		
750805	85		761108	100		
750818	95		761108	100		
750901	95		761122	100		
750915	100		761206	100		
751006	105		761206	100		
751020	105		761220	100		
751103	105		761220	100		
751117	105					
751201	105					
751215	105					

<sup>1</sup> Obtained from computer data tapes entitled Texas Instruments 1975 Impingement Data (Record Type E) and Texas Instruments 1976 Impingement Data (Record Type E).

<sup>2</sup> The format for DATE is year-month-day.

<sup>3</sup> The seasonally-varying, total body length which is used to discriminate between young-of-the-year and yearling white perch.

<sup>4</sup> The two year classes separated by DIVISION.

CHAPTER III

IMPINGEMENT IMPACT ESTIMATES FOR SEVEN HUDSON RIVER FISH SPECIES

TESTIMONY OF

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## SUMMARY

This testimony presents quantitative estimates of the direct impact of impingement at the Bowline, Lovett, Indian Point, Roseton, and Danskammer generating stations on seven Hudson River fish species: white perch, striped bass, alewife, blueback herring, American shad, Atlantic tomcod, and bay anchovy. Conditional impingement mortality rates ( $m_i$ ) were calculated for the 1974 year classes of white perch, striped bass, alewife, blueback herring, American shad, and Atlantic tomcod, and for the 1975 year classes of white perch, striped bass, American shad, and Atlantic tomcod. These rates are equivalent to estimates of the fractional reduction in abundance of each year class due to impingement, in the absence of compensation. Exploitation rates for the total impingeable bay anchovy population (adults + juveniles) residing above river mile 12 are presented for each month from May through October, 1974 and 1975. Rather than presenting single, "conservative," estimates of impact, as the utilities claim to have done, we present what we believe are realistic ranges of probable impacts for each species and year class. The highest impingement impact estimates obtained were for white perch, the lowest for American shad.

In addition to estimating the impacts that have actually been imposed on these fish populations, we estimated the impacts that would have occurred had closed-cycle cooling systems been installed at one or more of the three plants (Bowline, Indian Point, and Roseton) at issue in these proceedings. For this analysis we selected three species, white perch, Atlantic tomcod, and striped bass, and three cooling system configurations: closed-cycle cooling at all three plants, closed-cycle cooling at Bowline and Indian Point, and closed-cycle cooling at Indian Point alone. We found that greatly reduced impacts on all three species would have occurred had closed-cycle cooling systems been operating either at all three plants or only at Bowline and Indian Point. Closed-cycle cooling at Indian Point alone would have substantially reduced the impact of impingement on white perch and Atlantic tomcod, and would have moderately reduced the impact on striped bass.



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## 1. ANALYTICAL METHODS AND SOURCES OF INPUT DATA

Consultants for both the utilities and EPA have used the conditional impingement mortality rate as a measure of impingement impact. The primary reason for the usefulness of this measure is that it provides a direct estimate of the fractional reduction in year class abundance of vulnerable species, in the absence of compensation, caused by the impingement of juvenile fish. The properties of the conditional impingement mortality rate are discussed in detail by Barnthouse et al. (1979). In this section we compare the methods and data used by Texas Instruments (TI), Lawler, Matusky and Skelly (LMS), and ourselves to estimate conditional impingement mortality rates. In Section 2 we present our estimates of the input data (monthly impingement totals, initial numbers of vulnerable juveniles, and natural mortality rates) for six Hudson River fish species: striped bass, white perch, blueback herring, alewife, American shad, and Atlantic tomcod. Section 3 contains our estimates of the fractional reduction in year class abundance due to impingement for all of these species in 1974, and for striped bass, white perch, Atlantic tomcod, and American shad in 1975.

Meaningful conditional impingement mortality rates could not be computed for the bay anchovy, because meaningful estimates of the size of this population cannot be obtained from either TI or LMS data. This species is largely restricted to the lower estuary. Within the portion of the river sampled by TI, the highest densities of bay anchovy are generally found in the Yonkers (RM 12-23) and Tappan Zee (RM 24-33) regions (Exhibit EPA-198). These are the furthest downstream of TI's 12 river regions. An unknown, but presumably large, fraction of this population resides below River Mile 12 and is not sampled. Fluctuations in bay anchovy abundance indices calculated by TI may well be due as much to the movement of fish into and out of the Yonkers Region as to actual changes in the numbers of bay anchovies.

Since meaningful conditional impingement mortality rates could not be computed for this species, we computed impingement exploitation rates for the total population residing above River Mile 12.

The bay anchovy is the principal food species for bluefish, and is also fed on by striped bass (Exhibit EPA-198). Although our exploitation rates are not measures of the impact of impingement on the bay anchovy population as a whole, they can be validly interpreted as estimates of the reduction in the forage base available to piscivorous fishes inhabiting the Hudson River estuary above River Mile 12.

### 1.1 COMPARISON OF COMPUTATIONAL METHODS EMPLOYED BY TI, LMS, AND ORNL

Utility consultants have used two different methods of calculating conditional impingement mortality rates. The method used in Exhibit UT-3

was originally described by TI in Appendix F of the Multiplant Report (Texas Instruments 1975). That used by LMS in Exhibits UT-6 and UT-7 is described in Appendices 9.1B of Exhibits UT-6A and UT-7A. Although the two methods are conceptually similar, there are some significant differences in the data requirements of these models and the exact manner in which they are applied. In order to facilitate our comparison of these methods to that employed by ORNL, we use our notation to describe all three. Table 1 contains the symbols to be used in this discussion, their definitions, and the equivalent notation used in Exhibits UT-3, UT-6A, and UT-7A.

TI's method (Exhibit UT-3) requires as input data estimates of the following: the total number of juveniles alive at the time they first become vulnerable to impingement ( $N_0$ ), the total number of fish impinged during the period of vulnerability ( $I_T$ ), and the fraction of the initial number dying from all causes during the period of vulnerability ( $A$ ). The first step in TI's method is the computation of the impingement exploitation rate ( $u$ ), which is defined simply as the fraction of the initial number of vulnerable juveniles that are impinged and killed. Given the exploitation rate ( $u$ ) and the total fractional mortality ( $A$ ), TI calculates the conditional impingement mortality rate ( $m_I$ ) by solving the following two equations:

$$n = 1 - (1 - A)^{(1 - u/A)} \quad (1)$$

$$m_I = 1 - (1 - A)/(1 - n) \quad (2)$$

Although LMS' method is conceptually similar to that of TI, LMS employs an approximation that eliminates the need for an estimate of  $A$ . Instead, LMS' method requires an estimate of the average number of juveniles alive during the period of vulnerability ( $\bar{N}$ ). The conditional impingement mortality rate is given by:

$$m_I = I_T/\bar{N} \quad (3)$$

The calculation of  $\bar{N}$  requires periodic estimates of population size throughout the period of vulnerability. In Section 1.2 we present evidence indicating that the data used by LMS is of highly questionable reliability and is probably not suitable for this purpose.

The manner in which LMS' model is applied in Sections 10.4 of Exhibits UT-6 and UT-7 differs from TI's application in an important way. TI uses the initial number of impingeable juveniles as input data. The impingement totals used by TI are those corresponding to the months during which these juveniles are vulnerable to impingement. For example, in computing a conditional mortality rate for the 1974 year class of Atlantic tomcod, TI used the impingement estimates for the months of May through December 1974.

Table 1. Symbols and definitions used in ORNL, TI and LMS impingement impact models

ORNL symbol	TI <sup>a</sup> symbol	LMS <sup>b</sup> symbol	Definition
$I_T$	--c	--d	Total number of fish killed by impingement during the period of vulnerability of a given year class (ORNL and TI) or during a given calendar year (LMS).
$I_j$			Number of fish killed by impingement during month $i$ .
$N_0$	$N_0$		Initial population size, i.e., number of fish alive at start of period of vulnerability.
$N_j$			Number of fish alive at end of month $i$ .
$N$		--d	Average population size during period of vulnerability (or calendar year, as used by LMS).
$u$	$u_E$		Overall impingement exploitation rate, i.e., fraction of initial population that are killed by impingement ( $= I_T/N_0$ ).
$u_j$			Exploitation rate during month $i$ .
$m_I$	$m_I$	$m_I$	Overall conditional impingement mortality rate, i.e., fraction of initial population that would be killed by impingement in the absence of natural mortality.
$m_j$			Conditional impingement mortality rate during month $i$ .
$n$	$q_n$		Overall conditional natural mortality rate, i.e., fraction of initial population that would die during the period of vulnerability in the absence of impingement.
$n_j$			Conditional natural mortality rate during month $i$ .
$A$	$q_t$		Fraction of initial population dying from all causes during the period of vulnerability.
$A_j$			Fraction of initial population dying from all causes during month $i$ .
$D$			Daily rate of total mortality.

<sup>a</sup>Exhibit UT-3, Section 2-VI.

<sup>b</sup>Exhibits UT-6A and UT-7A, Appendices 9.1B.

<sup>c</sup>No symbol used for this quantity.

<sup>d</sup>Symbols and definitions in Appendices 9.1B of Exhibits UT-6A and UT-7A are those used in the entrainment application of the LMS model. The impingement application (Exhibits UT-6 and UT-7, Sections 10.4) is not formally documented.

The results of TI's calculations are estimates of the fractional reduction in year class abundance due to impingement. LMS' method is applied in an entirely different way. The abundance estimates are estimates for entire populations, not just the vulnerable components of the populations. For example, LMS' white perch estimates for all months include adult white perch, which are relatively less vulnerable to impingement, as well as the highly vulnerable young-of-the-year and yearlings. As another example, LMS' estimates of blueback herring abundance for the months of April through June are estimates of the abundance of yearlings and spawning adults; only the estimates for July through December include young-of-the-year.

Even more important, LMS calculates the conditional mortality rate not over the period of vulnerability of each year class, but over the calendar year. This procedure confounds data relating to the impact of impingement on several different year classes. For example, LMS computes a value of  $m_I$  for white perch in 1975 using abundance and impingement estimates for January-June, that reflect primarily the impact of power plants on the 1974 year class, along with estimates for July-December, that reflect the impact on the 1975 year class.

Because of this mixing of abundance and impingement estimates for different-aged fish, the "impingement cropping estimates" in Sections 10.4 of Exhibits UT-6 and UT-7 are not equivalent to estimates of the fractional reduction in year class abundance due to impingement. For this reason, we consider TI's method of calculating conditional impingement mortality rates to be superior to LMS'.

Both TI and LMS implicitly assume that  $m_I$  is constant throughout the period of vulnerability. However, the impingement rates of most species exhibit marked seasonal fluctuations, as is clearly demonstrated by the monthly impingement estimates contained in Section 2 of this Exhibit. Barnthouse et al. (1979) have shown that these fluctuations can cause substantial underestimates or overestimates of  $m_I$  if a method that assumes constancy of  $m_I$  is employed. The ORNL Empirical Impingement Model, used to derive the estimates of  $m_I$  in Section 3, takes seasonal variations in impingement into account by assuming that  $m_I$  is constant only within each month. Otherwise, our method is essentially identical to TI's. ORNL's Empirical Impingement Model has been described in detail by Barnthouse et al. (1979).

Using impingement totals ( $I_i$ ) and conditional natural mortality rates ( $n_i$ ) calculated separately for each month, we use Eq. (4) to calculate monthly values of the conditional impingement mortality rate ( $m_i$ ) in sequence.

$$m_i = 1 - [1 - (m_i + n_i - m_i n_i)]^{u_i / (m_i + n_i - m_i n_i)} \quad (4)$$

The first monthly exploitation rate ( $u_1$ ) is calculated from  $N_0$  and  $I_1$ . After Eq. (4) has been solved iteratively for the first month of vulnerability, the initial population size for the second month is calculated from Eq. (5):

$$N_1 = N_0(1 - m_1)(1 - n_1) \quad . \quad (5)$$

The above calculations are repeated for each successive month, and then the overall conditional impingement mortality rate is calculated as:

$$m_I = 1 - \prod_{i=1}^k (1 - m_i) \quad , \quad (6)$$

where  $k$  = number of months of vulnerability.

When natural mortality is high in comparison to impingement mortality, as is the case for nearly all of the species considered in this Exhibit (white perch is the only exception), the total mortality rate ( $A$ ) and the overall conditional natural mortality rate ( $n$ ) are essentially equal. For example, Barnthouse et al. (1979) computed an estimate of  $n$  for juvenile striped bass based on the estimate of  $A$  presented in Section 2-VI of Exhibit UT-3. The two values differed by only about 1% ( $A = 0.80$ ,  $n = 0.79$ ), a trivial difference in comparison to measurement error. The disparity between impingement mortality and natural mortality is even greater for Atlantic tomcod, blueback herring, alewife, and American shad than it is for striped bass, and consequently, the difference between estimates of  $A$  and  $n$  for these species would be even smaller. In our impact estimates (Section 3) we have therefore used estimates of total mortality ( $A$ ) derived from field data as estimates of natural mortality. The small numerical difference between  $A$  and  $n$  does not imply that impingement is insignificant, because it is not the increase in the fraction dying, but the decrease in the fraction surviving caused by impingement that is important. To illustrate this point we will consider a hypothetical fish population for which the conditional natural mortality rate during the period of vulnerability to impingement is equal to 0.9. Suppose that, for this population, the total mortality rate, including both natural and impingement mortality, is equal to 0.91. Numerically, the values of  $n$  and  $A$  for our hypothetical population are nearly identical. Nonetheless, the impact of impingement is not trivially small. Because  $n$  is equal to 0.9, in the absence of any impingement 10% of the juveniles alive at the beginning of the period of vulnerability would survive to the end of that period. However, because of the effects of impingement (as reflected in  $A$ ), only 9% actually do survive. This decrease in survival from 0.1 to 0.09 represents a definitely non-trivial 10% reduction in year class abundance caused by impingement.

All three of the above methods are derived from Ricker's (1975) theory of fishing mortality, specifically his "Type II Fishery." Thus, except for the utilities' assumption of constant  $m_I$ , we have no conceptual quarrel with their analytical methods. Our criticism of LMS' impingement impact assessments is directed at the data used by LMS and at the way in which LMS' method is applied, not at the method itself.

## 1.2 SOURCES OF INPUT DATA

The sources of impingement data and the various errors associated with estimates of the number of fish impinged and killed by power plants are discussed by Barnthouse (1979) in Exhibit EPA-205. Data relating to abundance and mortality in vulnerable fish species are available from several sources. The most important of these are: (1) TI's mark/recapture programs, (2) TI's Long River Survey and Fall Shoals Survey, (3) TI's Riverwide Beach Seine Survey, (4) TI's Interregional Bottom Trawl Survey, and (5) LMS' bottom trawl surveys in the Bowline, Lovett, and Roseton/Danskammer vicinities. TI has used mark/recapture techniques to estimate the fall abundance of juvenile white perch and striped bass and the winter abundance of spawning Atlantic tomcod. TI has also used various combinations of the Long River Survey, Fall Shoals Survey, and Riverwide Beach Seine Survey data to estimate the abundance of juvenile striped bass, white perch, Atlantic tomcod, and American shad. LMS has used its Bowline, Lovett, and Roseton/Danskammer near-field bottom trawl data to compute population estimates for white perch, blueback herring, Atlantic tomcod, and bay anchovy.

All of these estimates are subject to many kinds of errors, and without doubt, they are far less accurate than are estimates of the numbers of fish impinged. The mark/recapture estimates are probably the most reliable since they require no estimates of gear efficiency. Unfortunately, the mark/recapture population estimates for striped bass and Atlantic tomcod are not useable for the purpose of impingement impact assessment (see discussions in Appendix B). Abundance estimates for all species except white perch must be obtained from one or several of the TI and LMS fish sampling programs. Each species-specific abundance estimate has its own unique deficiencies, largely related to lack of correspondence between the regions and habitats sampled by TI and LMS and the regions and habitats inhabited by the fish themselves. These deficiencies are discussed on a species-by-species basis in Appendix B.

In this section discussion is limited to general deficiencies common to all population estimates obtained from fish survey data and to the comparative deficiencies of TI's and LMS' sampling programs. All of the estimates derived from this type of data are computed in essentially the same way:

- (1) The number of fish caught in each sample is converted to a measure of catch-per-unit-effort, with effort being defined in units of volume or area sampled. For some gears (TI's epibenthic sled and Tucker trawl) the effort can be measured directly by means of a flowmeter attached to the gear itself. For the beach seine and bottom trawl the effort must be estimated indirectly.
- (2) The catch/effort estimates are multiplied by the total area or volume of the sampled region in order to obtain estimates of the absolute number of fish in that region.

Both steps in the above procedure are subject to serious, even fatal, errors. Accurate measurement of the area or volume sampled by a beach seine or bottom trawl is not possible. TI has attempted to estimate the average area swept by the 100-ft beach seine; LMS has used the physical dimensions of its bottom trawl to estimate the average volume sampled during each haul. However, neither gear maintains a constant shape during sampling and neither gear can be deployed in an identical manner for each haul. The actual path of a beach seine and the actual dimensions of the mouth opening of a bottom trawl undoubtedly vary considerably from sample to sample.

A far more important source of error is gear efficiency: the fraction of the fish in the path of the gear that are actually caught. All of the catch/effort data used to compute abundance estimates are obtained with sampling gear of unknown and variable efficiency. The average efficiency of all of these gears is surely much less than 100%, but even with the aid of experimental tests, it is possible only to roughly estimate how much less. Even worse, the efficiency of any gear varies among species and among size-classes of fish within each species. Efficiency can vary from day to day because of variations in cloud cover or turbidity that influence the ability of the fish to detect the gear, and it can vary seasonally because of temperature-related variations in the fish's ability to evade capture. This problem is not unique to TI's and LMS' surveys and it does not imply that their data are useless. Even the best-designed collection program conducted with the best possible equipment by the best personnel must produce data that suffer in accuracy and precision because of poorly known and variable gear efficiency. This problem is simply an unavoidable source of error that must be acknowledged and kept in mind when the data are interpreted.

The second step in the computational procedure, that of scaling up the catch/effort data to absolute population estimates, is another source of serious error. Unlike the more or less unavoidable problems related to gear efficiency, the errors introduced in this step are largely a function of the sampling design employed by the contractor. With respect to appropriateness of sampling design, TI's collection programs are clearly superior to those of LMS for the purpose of estimating the riverwide abundance of Hudson River fish species. TI samples the entire length of the Hudson between River Miles 12 and 140. TI has divided the estuary into 12 longitudinal regions on the basis of morphometric characteristics such as depth, width, and

extent of shoals (Exhibit UT-4, Table 6.1-1). Each region is further subdivided into "strata" (shorezone, shoals, bottom, and channel) that roughly correspond to distinct habitats for fish. Rather than sampling at the same locations during every sampling period, TI collects samples at random locations within each stratum and region. TI's programs are designed primarily to measure the abundance of striped bass, and therefore the intensity of the sampling effort within regions and strata is determined by the expected distribution of striped bass life stages. To the extent that the distribution of other species differs from that of striped bass, population estimates obtained for these other species will be less reliable than are those obtained for striped bass.

TI has attempted to collect representative samples from all major habitat types within the Hudson River estuary between Yonkers and Albany. In contrast, LMS' sampling programs have never been designed for the purpose of estimating the riverwide abundance and distribution of any fish species. Their purpose is the monitoring of the relative abundance of various fish species in the immediate vicinities of four power plants: Bowline, Lovett, Roseton and Danskammer. LMS' samples are collected at a small number of fixed stations that, although they may be representative of conditions in the vicinities of the plants, may be highly unrepresentative of conditions a few miles up or downstream or on the other side of the river. LMS may be collecting fish from locations where the fish are, on the average, either unusually abundant or unusually scarce in comparison to their average abundance over the entire region in which the plants are located. As long as the data collected are used only to compare the relative abundances of different species and to monitor seasonal and/or annual variations in relative abundance at the fixed sampling stations, the representativeness or unrepresentativeness of those stations is of relatively minor importance. It is, however, of major importance when attempts are made to scale up the results to estimates of the absolute abundance of fish in a 40-mile-long segment of the estuary.

We will illustrate this problem with a single example: LMS' estimates of white perch abundance, contained in Sections 10.4 of Exhibits UT-6 and UT-7. These estimates were obtained by: (1) calculating the average catch-per-unit-volume of white perch in the bottom trawl samples collected during each month, and (2) multiplying this value by the volume of water contained in the bottom ten feet of the river, from shore to shore, over a 20-mile river segment (RM 30-50 for Bowline, RM 50-70 for Roseton).

LMS assures the reader (Exhibit UT-7, p. 10.4-3) that this procedure necessarily underestimates the true abundance of white perch, because it does not include fish residing above RM 70 and below RM 30, and also because it does not include fish located more than 10 feet from the bottom of the river. Despite these claims the estimates generated by LMS for 1975 are surprisingly high. According to Table 10.4-1 of Exhibit UT-7, the average abundance of white perch between River Miles 30 and 70 during 1975 was between 50.4 million and 84 million fish (calculated assuming, respectively, 50 and 30% gear efficiency). TI's mark/recapture program for 1975 indicated

the presence of only 30 million juvenile white perch in the entire Hudson in October 1975 and only 45 million in July (Exhibit UT-3, p. 2-VII-2). If, as the utilities assume on p. 2-VII-3 of Exhibit UT-3, juveniles represent 90% of the entire white perch population, then TI's data indicate that in July of 1975 only 50.0 million white perch were present in the entire Hudson River. Since July is the month of peak abundance of juvenile and adult white perch, the annual average population size would be considerably lower.

How can a supposedly "conservative" technique generate a population estimate that is higher than that obtained using a much more reliable method? It is, of course, possible that TI's mark/recapture estimate is erroneously low. In addition to reporting a best estimate of the abundance of juvenile white perch in October 1975 (i.e., 30 million), TI computed 95% confidence limits (21 to 45 million) around the best estimate. Under the assumptions of the Peterson mark/recapture method (the method used by TI), the probability that the true abundance of juvenile white perch in October 1975 was less than 21 million or greater than 45 million is only 5%; the probability that the true abundance was greater than 45 million is only 2.5%. If, despite the low probability, it is assumed that the upper 95% confidence limit associated with TI's estimate (45 million) represents the true abundance of juvenile white perch in October 1975, then it is possible to generate a maximum white perch population size that falls within the range of average estimates calculated by LMS. Van Winkle and Barnthouse (Exhibit EPA-206; Table 4) used this assumption to compute an upper bound on the abundance of juvenile white perch in July 1975: 52.0 to 62.9 million. If the total white perch population is 90% juveniles, then under the most generous possible assumptions the maximum abundance of white perch in 1975 could have been 58 to 70 million fish, within the range of average population estimates calculated by LMS.

It seems more likely, however, that it is LMS' estimate, rather than TI's, that is in error. If LMS were really measuring the number of white perch present in the Hudson, the monthly estimates in Table 10.4-1 would be highest in the late summer, when juveniles have grown to a size such that they can be caught by the bottom trawl. The estimates should then decline steadily until the following summer. The values in Table 10.4-1 of Exhibit UT-7 show no such pattern. Instead, the estimates are highest in the late fall, winter, and early spring. According to LMS' February 1975 estimate, 140 to 234 million white perch were present in the Hudson between River Miles 30 and 70, within ten feet of the river bottom.

We believe that these anomalous results can be accounted for in two ways. First, they may be due to the non-representativeness of LMS' sampling stations. For example, two of LMS' three bottom trawl stations in Haverstraw Bay (BID and BC), a region of high white perch abundance during the winter months, are located in water 20 to 30 feet deep (Exhibit UT-7A, p. 10.1A-1). According to p. 10.4-4 of Exhibit UT-7, this is the preferred depth of white perch during the winter. However, according to data provided to EPA on November 16, 1978 in response to an information request dated November 9, 1978, 68% of the Croton-Haverstraw region, which includes

Haverstraw Bay, is less than 20 feet deep. If, as LMS claims on p. 10.4-4 of Exhibit UT-7, white perch prefer deeper water during the winter, then these shallow areas may contain few or no white perch. By expanding the catch/effort estimates over the entire river bottom from shore to shore, LMS could be greatly overestimating the actual abundance of white perch in Haverstraw Bay.

Second, seasonal variations in gear efficiency may contribute to LMS' high winter population estimates. Although the efficiency of the trawl may well be only 30 to 50% during the warmer months when white perch are active, it surely must be much higher than that during the winter, when these fish are not merely sluggish, but according to Texas Instruments (1974), "semi-dormant." Assuming that gear efficiency is low throughout the year, when in fact it is high during the period when fish are most abundant in the area sampled, will tend to cause overestimates of the true population size.

If the average population sizes calculated by LMS bear any relationship to the true population size, we believe that this must be due to sheer accident rather than design. TI's riverwide sampling programs, especially the riverwide white perch mark/recapture program, provide more reliable data on the abundance of Hudson River fish species than do LMS' near-field sampling programs at Bowline, Lovett, Roseton, and Danskammer. The abundance and mortality estimates developed in Appendix B of this exhibit are based entirely on TI's data.

## 2. SUMMARY OF DATA USED TO ESTIMATE THE IMPACT OF IMPINGEMENT ON HUDSON RIVER FISH SPECIES

In this section we present the data used to assess the impact of impingement on seven Hudson River fish species: white perch, striped bass, alewife, blueback herring, American shad, Atlantic tomcod, and bay anchovy. The source of the white perch data is the testimony of Van Winkle and Barnthouse (Exhibit EPA-206). All other data have been extracted using sources and methods detailed in Appendices A and B of this testimony. Since the purpose of the direct impact assessment is the estimation of conditional impingement mortality rates ( $m_I$ ) for specific year classes of each species, only data that can be used to compute such estimates are presented here.

The year classes for which data are presented here are the 1974 and 1975 year classes of white perch, striped bass, American shad, Atlantic tomcod, and bay anchovy and the 1974 year class of alewife and blueback herring. As was noted in Section 1, estimation of  $m_I$  was not possible for bay anchovy. For this species the data presented are those required for estimating impingement exploitation rates for the total impingeable population for the months of May through October, 1974 and 1975; namely, monthly impingement totals and monthly estimates of the total number of adult and juvenile bay anchovy present above RM 12.

### 2.1 IMPINGEMENT ESTIMATES

Tables 2 through 13 contain the impingement estimates used to compute the conditional impingement mortality rates ( $m_I$ ) and the bay anchovy exploitation rates ( $u$ ) in Section 3. The data are organized by species and by year class within species. For example, Table 4 contains the number of striped bass belonging to the 1974 year class that were impinged during each month between July 1974 and June 1976, while Table 5 contains similar numbers for members of the 1975 year class impinged between July 1975 and June 1977. Except for bay anchovy, the estimates begin with the first month during which members of a given year class were impinged and end with the last month for which data are input to the Empirical Impingement model. For all species except Atlantic tomcod, we cut off the period of vulnerability of each year class after impingement rates for that year class have fallen to a negligibly low level. For Atlantic tomcod, we cut off the period of vulnerability at the end of the spawning season (approximately the end of January). The impingement of adults after the end of the spawning season has little or no effect on the reproductive capacity of the Atlantic tomcod population, since very few of these fish survive to reproduce a second time.

### 2.2 ABUNDANCE AND MORTALITY ESTIMATES

Tables 2 through 13 also contain the abundance and mortality estimates developed for the species considered in this testimony. For all species, at

Table 2. Input data used to compute conditional impingement mortality rates ( $m_I$ ) for the 1974 white perch year class<sup>a</sup>

Year and Month	Monthly impingement totals ( $I_i$ )		Monthly conditional natural mortality rates ( $n_j$ )		Initial population size ( $N_0$ )	
	2-year vulnerability <sup>b</sup>	3-year vulnerability <sup>c</sup>	High young-of-the-year mortality <sup>d</sup>	Low young-of-the-year mortality <sup>e</sup>	High young-of-the-year mortality <sup>f</sup>	Low young-of-the-year mortality <sup>g</sup>
1974						
JUL	3,486	3,486	0.064	0.028	16.8x10 <sup>6</sup>	13.9x10 <sup>6</sup>
AUG	14,887	14,887	0.128	0.057	(lower bound) <sup>h</sup>	
SEP	26,239	26,239	0.124	0.055	29.4x10 <sup>6</sup>	24.3x10 <sup>6</sup>
OCT	112,957	112,957	0.128	0.057	(best estimate) <sup>i</sup>	
NOV	245,492	245,492	0.124	0.055	54.5x10 <sup>6</sup>	45.1x10 <sup>6</sup>
DEC	607,434	607,343	0.128	0.057	(upper bound) <sup>j</sup>	
1975						
JAN	415,724	415,724	0.128	0.057		
FEB	270,751	270,751	0.116	0.052		
MAR	139,751	139,751	0.128	0.057		
APR	609,090	609,090	0.124	0.055		
MAY	91,910	91,910	0.128	0.057		
JUN	37,242	18,621	0.055	0.055		
JUL	22,126	11,063	0.057	0.057		
AUG	14,122	7,061	0.057	0.057		
SEP	19,924	9,962	0.055	0.055		
OCT	19,534	9,767	0.057	0.057		
NOV	28,005	14,002	0.055	0.055		
DEC	7,803	3,902	0.057	0.057		
1976						
JAN	38,078	19,039	0.057	0.057		
FEB	9,239	4,646	0.054	0.054		
MAR	12,444	6,222	0.057	0.057		
APR	14,103	7,052	0.055	0.055		
MAY	7,612	3,806	0.057	0.057		
JUN	--	13,507	0.055	0.055		
JUL	--	6,918	0.057	0.057		
AUG	--	3,385	0.057	0.057		
SEP	--	6,896	0.055	0.055		
OCT	--	12,838	0.057	0.057		
NOV	--	6,276	0.055	0.055		
DEC	--	24,051	0.057	0.057		
1977						
JAN	--	71,505	0.057	0.057		
FEB	--	21,779	0.052	0.052		
MAR	--	24,790	0.057	0.057		
APR	--	19,346	0.055	0.055		
MAY	--	28,182	0.057	0.057		

<sup>a</sup>From Van Winkle and Barnthouse 1979 (Exhibit EPA-206), Tables 6 and 7.

<sup>b</sup>All yearling and older white perch assumed to be yearlings.

<sup>c</sup>One-half of yearling and older white perch assumed to be yearlings; other one-half assumed to be 2-year olds.

<sup>d</sup>Values of  $n_j$  for July 1974-May 1975 computed using  $D = 0.0044$ ; values for all other months computed using  $D = 0.0019$ .

<sup>e</sup>Values of  $n_j$  for all months computed using  $D = 0.0019$ .

<sup>f</sup>Back-calculated from October 1 population size using  $D = 0.0044$ .

<sup>g</sup>Back-calculated from October 1 population size using  $D = 0.0019$ .

<sup>h</sup>Computed from lower 95% confidence limit around TI's mark/recapture population estimate (Exhibit UT-3, Section 2-VII).

<sup>i</sup>Computed from TI's mark/recapture population estimate (Exhibit UT-3, Section 2-VII).

<sup>j</sup>Computed from upper 95% confidence limit around TI's mark/recapture population estimate (Exhibit UT-3, Section 2-VII).

Table 3. Input data used to compute conditional impingement mortality rates ( $m_i$ ) for the 1975 white perch year class<sup>a</sup>

Year and Month	Monthly impingement totals ( $I_i$ )		Monthly conditional natural mortality rates ( $n_i$ )		Initial population size ( $N_0$ )	
	2-year vulnerability <sup>b</sup>	3-year vulnerability <sup>c</sup>	High young-of-the-year mortality <sup>d</sup>	Low young-of-the-year mortality <sup>e</sup>	High young-of-the-year mortality <sup>f</sup>	Low young-of-the-year mortality <sup>g</sup>
1975						
JUL	8,898	--	0.064	0.028	29.4x10 <sup>6</sup>	24.3x10 <sup>6</sup>
AUG	97,910	--	0.128	0.057	(lower bound) <sup>h</sup>	
SEP	83,980	--	0.124	0.055	41.9x10 <sup>6</sup>	34.7x10 <sup>6</sup>
OCT	93,888	--	0.128	0.057	(best estimate) <sup>i</sup>	
NOV	239,150	--	0.124	0.055	62.9x10 <sup>6</sup>	52.0x10 <sup>6</sup>
DEC	348,596	--	0.128	0.057	(upper bound) <sup>j</sup>	
1976						
JAN	589,206	--	0.128	0.057		
FEB	182,891	--	0.120	0.054		
MAR	130,261	--	0.128	0.057		
APR	111,820	--	0.124	0.055		
MAY	40,151	--	0.128	0.057		
JUN	27,014	--	0.055	0.055		
JUL	13,835	--	0.057	0.057		
AUG	6,770	--	0.057	0.057		
SEP	13,791	--	0.055	0.055		
OCT	25,676	--	0.057	0.057		
NOV	12,552	--	0.055	0.055		
DEC	48,102	--	0.057	0.057		
1977						
JAN	143,010	--	0.057	0.057		
FEB	43,558	--	0.052	0.052		
MAR	49,579	--	0.057	0.057		
APR	38,692	--	0.055	0.055		
MAY	56,365	--	0.057	0.057		

<sup>a</sup>From Van Winkle and Barnthouse 1979 (Exhibit EPA-206), Tables 6 and 7.

<sup>b</sup>All yearling and older white perch assumed to be yearlings.

<sup>c</sup>This case could not be studied due to lack of impingement data for the period January-June 1978.

<sup>d</sup>Values of  $n_i$  for July 1975-May 1976 computed using  $D = 0.0044$ ; values for all other months computed using  $D = 0.0019$ .

<sup>e</sup>Values of  $n_i$  for all months computed using  $D = 0.0019$ .

<sup>f</sup>Back-calculated from October 1 population size using  $D = 0.0044$ .

<sup>g</sup>Back-calculated from October 1 population size using  $D = 0.0019$ .

<sup>h</sup>Computed from lower 95% confidence limit around TI's mark/recapture population estimate (Exhibit UT-3, Section 2-VII).

<sup>i</sup>Computed from TI's mark/recapture population estimate (Exhibit UT-3, Section 2-VII).

<sup>j</sup>Computed from upper 95% confidence limit around TI's mark/recapture population estimate (Exhibit UT-3, Section 2-VII).

Table 4. Input data used to compute conditional impingement mortality rates ( $m_i$ ) for the 1974 striped bass year class<sup>a</sup>

Year and Month	Monthly impingement totals ( $I_i$ )	Monthly conditional natural mortality rates ( $n_i$ )		Initial population size ( $N_0$ )	
		High young-of-the-year mortality <sup>b</sup>	Low young-of-the-year mortality <sup>c</sup>	High young-of-the-year mortality <sup>d</sup>	Low young-of-the-year mortality <sup>e</sup>
1974					
JUL	2,538	0.064 <sup>f</sup>	0.028 <sup>f</sup>		
AUG	6,792	0.128	0.057	4.08x10 <sup>6</sup>	3.92x10 <sup>6</sup>
SEP	5,572	0.124	0.055	(lower bound)	
OCT	6,212	0.128	0.057	20.39x10 <sup>6</sup>	19.59x10 <sup>6</sup>
NOV	5,107	0.124	0.055	(upper bound)	
DEC	19,899	0.128	0.057		
1975					
JAN	25,508	0.128	0.057		
FEB	14,039	0.116	0.052		
MAR	14,815	0.128	0.057		
APR	36,518	0.124	0.055		
MAY	774	0.128	0.057		
JUN	2,589	0.055	0.055		
JUL	2,929	0.057	0.057		
AUG	878	0.057	0.057		
SEP	552	0.055	0.055		
OCT	343	0.057	0.057		
NOV	318	0.055	0.055		
DEC	271	0.057	0.057		
1976					
JAN	389	0.057	0.057		
FEB	180	0.054	0.054		
MAR	0	0.057	0.057		
APR	0	0.055	0.055		
MAY	29	0.057	0.057		
JUN	61	0.055	0.055		

<sup>a</sup>From Appendices A and B.

<sup>b</sup>Values of  $n_i$  for July 1974-May 1975 computed using  $D = 0.0044$ ; values for all other months computed using  $D = 0.0019$ .

<sup>c</sup>Values of  $n_i$  for all months computed using  $D = 0.0019$ .

<sup>d</sup>Back-calculated from August 1 population size using  $D = 0.0044$ .

<sup>e</sup>Back-calculated from August 1 population size using  $D = 0.0019$ .

<sup>f</sup>Vulnerability to impingement assumed to begin on July 16.

Table 5. Input data used to compute conditional impingement mortality rates ( $m_i$ ) for the 1975 striped bass year class<sup>a</sup>

Year and Month	Monthly impingement totals ( $I_i$ )	Monthly conditional natural mortality rates ( $n_i$ )		Initial population size ( $N_0$ )	
		High young-of-the-year mortality <sup>b</sup>	Low young-of-the-year mortality <sup>c</sup>	High young-of-the-year mortality <sup>d</sup>	Low young-of-the-year mortality <sup>e</sup>
1975					
JUL	8,490	0.064 <sup>f</sup>	0.028 <sup>f</sup>		
AUG	8,403	0.128	0.057	5.69x10 <sup>6</sup>	5.46x10 <sup>6</sup>
SEP	5,838	0.124	0.055	(lower bound)	
OCT	2,265	0.128	0.057	28.43x10 <sup>6</sup>	27.32x10 <sup>6</sup>
NOV	2,251	0.124	0.055	(upper bound)	
DEC	9,949	0.128	0.057		
1976					
JAN	13,005	0.128	0.057		
FEB	2,520	0.120	0.054		
MAR	4,404	0.128	0.057		
APR	9,251	0.124	0.055		
MAY	794	0.128	0.057		
JUN	4,943	0.055	0.055		
JUL	3,723	0.057	0.057		
AUG	1,407	0.057	0.057		
SEP	895	0.055	0.055		
OCT	634	0.057	0.057		
NOV	136	0.055	0.055		
DEC	217	0.057	0.057		
1977					
JAN	760	0.057	0.057		
FEB	498	0.052	0.052		
MAR	1	0.057	0.057		
APR	0	0.055	0.055		
MAY	40	0.057	0.057		
JUN	13	0.055	0.055		

<sup>a</sup>From Appendices A and B.

<sup>b</sup>Values of  $n_i$  for July 1975-May 1976 computed using  $D = 0.0044$ ; values for all other months computed using  $D = 0.0019$ .

<sup>c</sup>Values of  $n_i$  for all months computed using  $D = 0.0019$ .

<sup>d</sup>Back-calculated from August 1 population size using  $D = 0.0044$ .

<sup>e</sup>Back-calculated from August 1 population size using  $D = 0.0019$ .

<sup>f</sup>Vulnerability to impingement assumed to begin on July 16.

Table 6. Input data used to compute conditional impingement mortality rates ( $m_i$ ) for the 1974 alewife year class<sup>a</sup>

Year and Month	Monthly impingement totals ( $I_i$ )	Monthly conditional natural mortality rates ( $n_i$ )				Initial Population Size ( $N_0$ )
		Highest young-of-the-year mortality <sup>b</sup>	High young-of-the-year mortality <sup>c</sup>	Intermediate young-of-the-year mortality <sup>d</sup>	Low young-of-the-year mortality <sup>e</sup>	
1974						
JUL	11,066	0.352	0.262	0.128	0.057	4.0x10 <sup>6</sup> (lower bound) 20.0x10 <sup>6</sup> (upper bound)
AUG	38,338	0.352	0.262	0.128	0.057	
SEP	20,181	0.343	0.255	0.124	0.055	
OCT	49,098	0.352	0.262	0.128	0.057	
NOV	14,511	0.124	0.124	0.124	0.055	
DEC	2,091	0.128	0.128	0.128	0.057	
1975						
JAN	76	0.128	0.128	0.128	0.057	
FEB	692	0.116	0.116	0.116	0.052	
MAR	161	0.128	0.128	0.128	0.057	
APR	1,174	0.124	0.124	0.124	0.055	
MAY	2,208	0.128	0.128	0.128	0.057	
JUN	4,088	0.055	0.055	0.055	0.055	
JUL	2,062	0.057	0.057	0.057	0.057	
AUG	571	0.057	0.057	0.057	0.057	
SEP	2,410	0.055	0.055	0.055	0.055	
OCT	2,170	0.057	0.057	0.057	0.057	
NOV	608	0.055	0.055	0.055	0.055	
DEC	123	0.057	0.057	0.057	0.057	
1976						
JAN	0	0.057	0.057	0.057	0.057	
FEB	34	0.054	0.054	0.054	0.054	
MAR	16	0.057	0.057	0.057	0.057	
APR	65	0.055	0.055	0.055	0.055	
MAY	252	0.057	0.057	0.057	0.057	
JUN	95	0.055	0.055	0.055	0.055	
JUL	0	0.057	0.057	0.057	0.057	
AUG	0	0.057	0.057	0.057	0.057	
SEP	0	0.055	0.055	0.055	0.055	
OCT	0	0.057	0.057	0.057	0.057	
NOV	0	0.055	0.055	0.055	0.055	
DEC	0	0.057	0.057	0.057	0.057	
1977						
JAN	0	0.057	0.057	0.057	0.057	
FEB	0	0.052	0.052	0.052	0.052	
MAR	7	0.057	0.057	0.057	0.057	
APR	1,380	0.055	0.055	0.055	0.055	
MAY	9,216	0.057	0.057	0.057	0.057	
JUN	897	0.055	0.055	0.055	0.055	

<sup>a</sup>From Appendices A and B.

<sup>b</sup>Values of  $n_i$  for July-October 1974 computed assuming  $D = 0.0140$ ; values of  $n_i$  for November 1974-May 1975 computed assuming  $D = 0.0044$ ; all other values computed assuming  $D = 0.0019$ .

<sup>c</sup>Values of  $n_i$  for July-October 1974 computed assuming  $D = 0.0098$ ; values of  $n_i$  for November 1974-May 1975 computed assuming  $D = 0.0044$ ; all other values computed assuming  $D = 0.0019$ .

<sup>d</sup>Values of  $n_i$  for July 1974-May 1975 computed assuming  $D = 0.0044$ ; all other values computed assuming  $D = 0.0019$ .

<sup>e</sup>All values of  $n_i$  computed assuming  $D = 0.0019$ .

Table 7. Input data used to compute conditional impingement mortality rates ( $m_i$ ) for the 1974 blueback herring year class<sup>a</sup>

Year and Month	Monthly impingement totals ( $I_j$ )	Monthly conditional natural mortality rates ( $n_j$ )			Initial population size ( $N_0$ )
		High young-of-the-year mortality <sup>b</sup>	Intermediate young-of-the-year mortality <sup>c</sup>	Low young-of-the-year mortality <sup>d</sup>	
1974					
JUL	1,903	0.262	0.128	0.057	29.0x10 <sup>6</sup> (lower bound) 145.0x10 <sup>6</sup> (upper bound)
AUG	7,957	0.262	0.128	0.057	
SEP	66,055	0.255	0.124	0.055	
OCT	182,354	0.262	0.128	0.057	
NOV	148,688	0.124	0.124	0.055	
DEC	877	0.128	0.128	0.057	
1975					
JAN	208	0.128	0.128	0.057	
FEB	674	0.116	0.116	0.052	
MAR	325	0.128	0.128	0.057	
APR	7,376	0.124	0.124	0.055	
MAY	5,640	0.128	0.128	0.057	
JUN	5,100	0.055	0.055	0.055	
JUL	754	0.057	0.057	0.057	
AUG	104	0.057	0.057	0.057	
SEP	1,401	0.055	0.055	0.055	
OCT	10,436	0.057	0.057	0.057	
NOV	0	0.055	0.055	0.055	
DEC	0	0.057	0.057	0.057	
1976					
JAN	72	0.057	0.057	0.057	
FEB	0	0.054	0.054	0.054	
MAR	0	0.057	0.057	0.057	
APR	154	0.055	0.055	0.055	
MAY	34	0.057	0.057	0.057	
JUN	24	0.055	0.055	0.055	
JUL	910	0.057	0.057	0.057	
AUG	15	0.057	0.057	0.057	
SEP	0	0.055	0.055	0.055	
OCT	0	0.057	0.057	0.057	
NOV	0	0.055	0.055	0.055	
DEC	0	0.057	0.057	0.057	
1977					
JAN	24	0.057	0.057	0.057	
FEB	0	0.052	0.052	0.052	
MAR	0	0.057	0.057	0.057	
APR	702	0.055	0.055	0.055	
MAY	12,053	0.057	0.057	0.057	
JUN	6,958	0.055	0.055	0.055	

<sup>a</sup>From Appendices A and B.

<sup>b</sup>Values of  $n_j$  for July-October 1974 computed assuming  $D = 0.0098$ ; values of  $n_j$  for November 1974-May 1975 computed assuming  $D = 0.0044$ ; all other values computed assuming  $D = 0.0019$ .

<sup>c</sup>Values of  $n_j$  for July 1974-May 1975 computed assuming  $D = 0.0044$ ; all other values computed assuming  $D = 0.0019$ .

<sup>d</sup>All values of  $n_j$  computed assuming  $D = 0.0019$ .

Table 8. Input data used to compute conditional impingement mortality rates ( $m_i$ ) for the 1974 American shad year class<sup>a</sup>

Year and Month	Monthly impingement totals ( $I_i$ )	Monthly conditional natural mortality rates ( $n_i$ ) <sup>b</sup>	Initial population size ( $N_0$ )
1974			
JUN	6,035	0.128 <sup>c</sup>	
JUL	7,256	0.246	15.6x10 <sup>6</sup>
AUG	6,121	0.246	(lower bound)
SEP	4,009	0.239	78.0x10 <sup>6</sup>
OCT	8,268	0.246	(upper bound)
NOV	4,290	0.124	
DEC	109	0.128	
1975			
JAN	192	0.128	
FEB	180	0.116	
MAR	21	0.128	
APR	157	0.124	
MAY	0	0.128	

<sup>a</sup>From Appendices A and B.

<sup>b</sup>Values of  $n_i$  for June-October computed using  $D = 0.0091$ ; all other values computed using  $D = 0.0044$ .

<sup>c</sup>Vulnerability to impingement assumed to begin on June 16.

Table 9. Input data used to compute conditional impingement mortality rates ( $m_I$ ) for the 1975 American shad year class<sup>a</sup>

Year and Month	Monthly impingement totals ( $I_j$ )	Monthly conditional natural mortality rates ( $n_j$ ) <sup>b</sup>	Initial population size ( $N_0$ )
1975			
JUN	33	0.178 <sup>c</sup>	
JUL	19,932	0.334	16.0x10 <sup>6</sup>
AUG	12,869	0.334	(lower bound)
SEP	21,447	0.325	80.0x10 <sup>6</sup>
OCT	3,415	0.334	(upper bound)
NOV	3,967	0.124	
DEC	155	0.128	
1975			
JAN	17	0.128	
FEB	0	0.120	
MAR	17	0.128	
APR	9	0.124	
MAY	7	0.128	

<sup>a</sup>From Appendices A and B.

<sup>b</sup>Values of  $n_j$  for June-October 1975 computed using  $D = 0.0131$ ; all other values computed using  $D = 0.0044$ .

<sup>c</sup>Vulnerability to impingement assumed to begin on June 16.

Table 10. Input data used to compute conditional impingement mortality rates ( $m_I$ ) for the 1974 Atlantic tomcod year class<sup>a</sup>

Year and Month	Monthly impingement totals ( $I_j$ )	Monthly conditional natural mortality rates ( $n_j$ ) <sup>b</sup>	Initial population size ( $N_0$ )
1974			
MAY	89,288	0.232 <sup>c</sup>	
JUN	983,817	0.372	
JUL	551,670	0.382	199.8x10 <sup>6</sup>
AUG	458,263	0.382	(lower bound)
SEP	288,743	0.372	999.0x10 <sup>6</sup>
OCT	18,617	0.382	(upper bound)
NOV	1,586	0.372	
DEC	40,091	0.382	
1975			
JAN	32,273	0.382	

<sup>a</sup>From Appendices A and B.

<sup>b</sup>All values of  $n_j$  computed assuming  $D = 0.0155$ .

<sup>c</sup>Vulnerability to impingement assumed to begin on May 15.

Table 11. Input data used to compute conditional impingement mortality rates ( $m_I$ ) for the 1975 Atlantic tomcod year class<sup>a</sup>

Year and Month	Monthly impingement totals ( $I_i$ )	Monthly conditional natural mortality rates ( $n_j$ )		Initial population size ( $N_0$ )
		1975 mortality <sup>b</sup>	1974 mortality <sup>c</sup>	
1975				
MAY	5,183	0.340 <sup>d</sup>	0.232 <sup>d</sup>	
JUN	204,346	0.519	0.372	
JUL	105,143	0.531	0.382	86.7x10 <sup>6</sup>
AUG	84,594	0.531	0.382	(lower bound)
SEP	112,804	0.519	0.372	433.5x10 <sup>6</sup>
OCT	2,560	0.531	0.382	(upper bound)
NOV	3,226	0.519	0.372	
DEC	12,127	0.531	0.382	
1976				
Jan	9,908	0.531	0.382	

<sup>a</sup>From Appendices A and B.

<sup>b</sup>All values of  $n_j$  computed assuming  $D = 0.0244$ .

<sup>c</sup>All values of  $n_j$  computed assuming  $D = 0.0155$ .

<sup>d</sup>Vulnerability to impingement assumed to begin on May 15.

Table 12. Input data used to compute monthly exploitation rates for bay anchovy, May-October 1974<sup>a</sup>

Year and Month	Monthly impingement totals ( $I_j$ ) <sup>b</sup>	Total population size <sup>b</sup>	
		Lower bound	Upper bound
1974			
MAY	1,259	$19.9 \times 10^6$	$99.5 \times 10^6$
JUN	62,807	$15.9 \times 10^6$	$79.5 \times 10^6$
JUL	212,933	$5.9 \times 10^6$	$29.5 \times 10^6$
AUG	197,326	$23.3 \times 10^6$	$116.5 \times 10^6$
SEP	146,314	$17.1 \times 10^6$	$85.5 \times 10^6$
OCT	27,382	$7.6 \times 10^6$	$38.0 \times 10^6$

<sup>a</sup>From Appendices A and B.

<sup>b</sup>Adults + juveniles.

Table 13. Input data used to compute monthly exploitation rates for bay anchovy, May-October 1975<sup>a</sup>

Year and Month	Monthly impingement totals ( $I_j$ ) <sup>b</sup>	Total population size <sup>b</sup>	
		Lower bound	Upper bound
1975			
MAY	80	$10.4 \times 10^6$	$52.0 \times 10^6$
JUN	11,303	$5.7 \times 10^6$	$28.5 \times 10^6$
JUL	172,280	$4.7 \times 10^6$	$23.5 \times 10^6$
AUG	260,008	$14.1 \times 10^6$	$70.5 \times 10^6$
SEP	159,823	$23.6 \times 10^6$	$118.0 \times 10^6$
OCT	51,484	$6.1 \times 10^6$	$30.5 \times 10^6$

<sup>a</sup>From Appendices A and B.

<sup>b</sup>Adults + juveniles.

least two estimates of the abundance of each year class are presented, one a maximum estimate and the other a minimum estimate. The minimum estimates for all species except white perch are population estimates obtained directly from TI's Long River Survey or beach seine survey data with no adjustments for gear efficiency. Since none of TI's gears is 100% efficient at catching juvenile fish (see discussion in Section 1.2), we believe that the true abundances were higher than these minimum estimates. The maximum estimates for all species except white perch were obtained by adjusting the minimum estimates to account for gear efficiency, which was assumed to be 20%. Since the efficiencies of TI's gears at catching these species are probably not lower than 20%, and may be well higher (see discussions in Appendix B), we believe that the true abundances were lower than these maximum estimates.

The source of the abundance estimates for white perch is TI's mark/recapture program. The maximum and minimum abundance estimates for the 1974 and 1975 year classes of this species are the upper and lower 95% confidence limits around the mark/recapture population estimates presented in Section 2-VII of Exhibit UT-3. Under the assumptions of the method of computation used by TI (the Peterson method), the probability that the true abundance of the 1974 or 1975 year class was greater than the maximum estimate or smaller than the minimum estimate is only 5%. In addition to the upper and lower 95% confidence limits, we used TI's mark/recapture population estimates themselves (referred to here as the "best" estimates, since they are the most probable values under the assumptions of the mark/recapture method) to compute values of  $m_1$  for white perch.

Multiple estimates of monthly conditional natural mortality rates are presented in Tables 2 through 11 for all year classes, except for the 1974 and 1975 American shad year classes, and the 1974 Atlantic tomcod year class. Since conditional impingement mortality rates were not computed for bay anchovy, natural mortality rates were not computed for this species.

Upper and lower bounds on young-of-the-year mortality of white perch were obtained from the testimony of Van Winkle and Barnthouse (Exhibit EPA-206). Similar estimates for striped bass are developed in Appendix B. Several sets of estimates for alewife and blueback herring are presented in Tables 6 and 7. The uncertainty associated with the empirically derived mortality estimates for these two species is high. Moreover, since substantial numbers of these fish are impinged at age three, the results obtained from application of the Empirical Impingement Model are unusually sensitive to the values chosen for this parameter. Some of the model runs for these two species (particularly alewife) produced what appeared to be unrealistically low estimates of the number of fish surviving at the end of the three-year period of vulnerability. It is possible (and, for alewife, probable) that the empirically derived mortality estimates for alewife and blueback herring are unrealistically high. Therefore, several model runs were made for each of these two species using assumed, rather than empirically derived, mortality rates. For both species values of  $m_1$  were computed assuming that juvenile mortality during the entire first year of vulnerability is equal to the upper bound for the natural mortality of

young-of-the-year white perch and striped bass ( $D = 0.0044$ ). Another set of runs was made assuming that mortality throughout the entire period of vulnerability is equal to the value derived by Van Winkle and Barnthouse ( $D = 0.0019$ ) for yearling and older white perch. Finally, estimates of  $m_T$  for alewife were computed using the early juvenile (July-October) mortality rate derived empirically for blueback herring. No special significance should be attached to the actual values assumed for mortality rates. Our intent was to select intermediate and low values for these rates in order to obtain realistic model output. The particular estimates that were used for this purpose were chosen solely for the sake of convenience.

Table 14 contains estimates of alewife spawning stock size in 1974 and 1975 and of Atlantic tomcod spawning stock size during the winters of 1974-75 and 1975-76. These estimates were used as a check on the validity of the values of initial abundance and mortality developed in Appendix B. As is discussed in more detail in Section 3, the comparison of model output to the values presented in Table 14 indicated that some combinations of initial abundance and mortality estimates produced unrealistic results when input to the Empirical Impingement Model.

Table 13 contains monthly estimates of the minimum and maximum number of impingeable bay anchovy (adults + juveniles) present above RM 12 from May through October of 1974 and 1975. These estimates were used to compute monthly exploitation rates for this species.

Table 14. Alewife and Atlantic tomcod spawning stock estimates used to assess reliability of model output

Year	Alewife	Atlantic tomcod
1974	$0.94 \times 10^6$ <sup>a</sup>	$2.47 \times 10^6$ <sup>b</sup>
1975	$0.98 \times 10^6$ <sup>a</sup>	$3.51 \times 10^6$ <sup>c</sup>

<sup>a</sup>Estimated minimum spawning stock present in the Hudson River shorezone in May, computed from TI Riverwide Beach Seine Survey data, unadjusted for gear efficiency.

<sup>b</sup>From Exhibit UT-4, Table 14.4-1.

<sup>c</sup>From TI 1975 Year Class Report (Texas Instruments 1978), Table B-102.

### 3. DIRECT IMPINGEMENT IMPACT ASSESSMENTS

Ranges of possible values of  $m_I$  for white perch, striped bass, alewife, blueback herring, American shad, and Atlantic tomcod were generated by applying the Empirical Impingement Model to all possible combinations of initial abundance, natural mortality, and impingement estimates for each year class. The results of these model runs are described on a species-by-species basis in Sections 3.1 through 3.6. Where results of some runs (for alewife, blueback herring, and Atlantic tomcod) were determined to be unrealistic, we have included a discussion of the rationale for excluding those results.

Our purpose in generating these ranges was to set probable upper and lower bounds on the impact of impingement on each year class. For all species except white perch, two conditions lead to high estimates of  $m_I$ : low initial population size and high natural mortality. Conversely, high initial population size and low natural mortality lead to low estimates of  $m_I$ . For white perch, two alternative assumptions were made about the length of the period of vulnerability to impingement; these constitute a third set of conditions affecting the value of  $m_I$ . The assumption of three years of vulnerability leads to high estimates of  $m_I$ ; the assumption of two years of vulnerability leads to low estimates of  $m_I$ . By combining estimates of initial abundance that are probably lower than the actual values with estimates of natural mortality that are probably higher than the actual values (and, for white perch, with the assumption of three years of vulnerability to impingement), we produced estimates of  $m_I$  that are probably higher than the actual impacts on these year classes. By combining estimates of initial abundance that are probably higher than the actual values with estimates of natural mortality that are probably lower than the actual values (and, for white perch, with the assumption of two years of vulnerability to impingement), we produced estimates of  $m_I$  that are probably lower than the actual impacts on these year classes. We refer to the ranges of impact estimates produced in this way as the "maximum ranges" of impact on each year class. Although we cannot rule out the possibility that the true impacts might have fallen outside our ranges, we believe that it is most probable that the impacts that were actually imposed on these year classes lie within our maximum ranges. As the data available for estimating conditional impingement mortality rates for alewife and blueback herring are less adequate than those available for the other species, our maximum ranges for these two clupeids are less certain than are those for white perch, striped bass Atlantic tomcod and American shad.

Section 3.7 presents the monthly exploitation rates computed for bay anchovy. Maximum ranges of exploitation rates for the months of May through October, 1974 and 1975, were generated using the minimum and maximum total population estimates presented in Table 13.

### 3.1 WHITE PERCH

Table 15 contains results of the 12 model runs performed for the 1974 white perch year class and the 6 runs performed for the 1975 year class. Six runs, corresponding to the assumption of three years of vulnerability to impingement, could not be performed for the 1975 year class due to the lack of 1978 impingement data. For the 1974 year class, three estimates of  $N_0$  (maximum, minimum, and best estimates) and two estimates of young-of-the-year mortality were used in combination with two sets of impingement totals (corresponding to assumptions of two years and three years of vulnerability). For the 1975 year class, three estimates of  $N_0$ , two estimates of young-of-the-year mortality, and one set of impingement estimates (corresponding to two years of vulnerability) were used.

Because of the existence of apparently reliable mark/recapture population estimates and of yearling and adult mortality estimates computed using the catch-curve-method (Exhibit EPA-206), the data available on the initial abundance and mortality of the 1974 and 1975 white perch year classes is without doubt better than that available for any of the other species considered here. Since no estimates of the abundance of two-year-old and three-year-old white perch are available, it was not possible to check the validity of the model output as we did for alewife and Atlantic tomcod. For these reasons, although some of the estimates of  $m_1$  are quite high, none could be excluded as being unrealistically high. However, for this species we computed a probable range, as well as a maximum range, of impact estimates. As was discussed in the introduction to Section 3, three conditions lead to high estimates of  $m_1$ : low population size, high natural mortality, and three years of vulnerability to impingement. Conversely, high population size, low mortality, and two years of vulnerability lead to low estimates of  $m_1$ . It is possible, though unlikely, that all three of the conditions promoting high impact or all three of the conditions promoting low impact are the conditions corresponding most closely to reality. For example, it is possible that the true initial abundance of the 1974 year class was close to our minimum abundance estimate, that young-of-the-year mortality for this year class was close to 80% (our high mortality rate), and that approximately half of the yearling and older white perch impinged between June 1976 and May 1977 were three-year-olds belonging to the 1974 year class. However, it is a priori more likely that some of the existing conditions were those favoring high impacts while others favored low impacts. Of the eight possible combinations for each year class of high and low abundance, high and low mortality, and two-year or three-year vulnerability, six combinations result in values of  $m_1$  that are intermediate between the values computed for the two extreme combinations. Therefore, we have derived a probable range of values of  $m_1$  for the 1974 and 1975 white perch year classes by excluding the estimates derived from the following combinations of input data: low initial abundance, high young-of-the-year mortality, and three years of vulnerability; and high initial abundance, low young-of-the-year mortality, and two years of vulnerability. Both the maximum range of  $m_1$  and the probable range for each year class are presented in Section 4 (Table 23).

Table 15. Estimates of conditional impingement mortality rates ( $m_I$ ) for the 1974 and 1975 white perch year classes

Years of vulnerability	Relative initial population size	Natural mortality	1974 Year class			1975 Year class		
			Initial population size ( $N_0$ ) <sup>a</sup>	Final population size <sup>b</sup>	Conditional impingement mortality rate ( $m_I$ )	Initial population size ( $N_0$ ) <sup>a</sup>	Final population size <sup>c</sup>	Conditional impingement mortality rate ( $m_I$ )
2	High	Low	45.1x10 <sup>6</sup>	11.1x10 <sup>6</sup>	0.095 <sup>d</sup>	52.0x10 <sup>6</sup>	13.1x10 <sup>6</sup>	0.077 <sup>d</sup>
2	High	High	54.5x10 <sup>6</sup>	5.8x10 <sup>6</sup>	0.137	62.9x10 <sup>6</sup>	6.8x10 <sup>6</sup>	0.115
2	Best estimate	Low	24.3x10 <sup>6</sup>	5.5x10 <sup>6</sup>	0.177	34.7x10 <sup>6</sup>	8.4x10 <sup>6</sup>	0.116
2	Best estimate	High	29.4x10 <sup>6</sup>	2.7x10 <sup>6</sup>	0.255	41.9x10 <sup>6</sup>	4.3x10 <sup>6</sup>	0.172
2	Low	Low	13.9x10 <sup>6</sup>	2.6x10 <sup>6</sup>	0.309	24.3x10 <sup>6</sup>	5.5x10 <sup>6</sup>	0.166
2	Low	High	16.8x10 <sup>6</sup>	1.1x10 <sup>6</sup>	0.446	29.4x10 <sup>6</sup>	2.7x10 <sup>6</sup>	0.245
3	High	Low	45.1x10 <sup>6</sup>	5.4x10 <sup>6</sup>	0.119	--	--	--
3	High	High	54.5x10 <sup>6</sup>	2.8x10 <sup>6</sup>	0.181	--	--	--
3	Best estimate	Low	24.3x10 <sup>6</sup>	2.6x10 <sup>6</sup>	0.221	--	--	--
3	Best estimate	High	29.4x10 <sup>6</sup>	1.2x10 <sup>6</sup>	0.336	--	--	--
3	Low	Low	13.9x10 <sup>6</sup>	1.2x10 <sup>6</sup>	0.386	--	--	--
3	Low	High	16.8x10 <sup>6</sup>	0.4x10 <sup>6</sup>	0.588 <sup>d</sup>	--	--	--

<sup>a</sup>Period of vulnerability assumed to begin on July 16.

<sup>b</sup>For two years of vulnerability, the number of surviving two-year-olds on June 1, 1976; for three years of vulnerability, the number of surviving three-year-olds on June 1, 1977.

<sup>c</sup>For two years of vulnerability, the number of surviving two-year-olds on June 1, 1977.

<sup>d</sup>Included in maximum range of conditional impingement mortality rates, but excluded from probable range.

### 3.2 STRIPED BASS

Eight model runs were performed for striped bass, four each for the 1974 and 1975 year classes. None of the runs produced estimates of  $m_I$  or of the number of juveniles alive after two years of vulnerability that seem improbably high or low. TI has estimated (Exhibit UT-4, p. 7.166) that on the average the number of striped bass juveniles surviving to the yearling stage is about 1.2 million. If about 50% of striped bass yearlings survive to two years of age, then even the lowest number of surviving two-year-olds produced by the impingement model (430,000) is consistent with TI's population estimate of yearlings. Although many of the runs produced estimates of two-year-old abundance far higher than is consistent with TI's estimate, it is quite possible that it is TI's result that is in error. TI could not directly estimate the number of striped bass yearlings. Instead, TI obtained an extrapolated estimate assuming a juvenile population size of six million in the fall and an annual total mortality of 80% (Exhibit UT-4, p. 7.161). Since the actual number of striped bass juveniles belonging to the 1974 and 1975 year classes may have been much higher than six million and their mortality may have been lower than 80% (see discussion in Appendix B), TI's estimate of yearling abundance may be substantially lower than the actual abundances of the 1974 and 1975 year classes at age one. We therefore cannot exclude any of the estimates of  $m_I$  as being unrealistically low or high. Table 16 contains the results of all four runs for each year class.

### 3.3 ALEWIFE

Eight separate model runs were performed for the 1974 alewife year class. The first two used the empirically derived estimates of  $N_0$  and  $D$  developed in Appendix B. Both of these runs produced estimates of the number of surviving three-year-olds that seemed to be suspiciously low (40,000 to 310,000). For this species it was possible to obtain rough estimates of the number of adult alewives from TI's Riverwide Beach Seine Survey data. These fish spawn in shallow water and large numbers of them are caught in TI's beach seine hauls during May. According to data extracted from TI's fisheries data tapes for 1974 and 1975 (provided to EPA on October 21, 1977, following an information request dated October 12, 1977), 1754 adult alewives were caught by beach seine in May 1974, and 1865 were caught in May 1975. We used these beach seine data to compute estimates of the average number of adult alewives present in shorezone areas of the Hudson River in May of 1974 and 1975. The computation of these estimates is described in Appendix B. According to our calculations, a minimum of about 1 million adult alewives were present in the Hudson River shorezone in May of both years (Table 14). An examination of the numbers of three-year-old alewives impinged during April-June of the years 1975-77 (Table 17) shows that the number impinged in 1977, the year in which members of the 1974 year class were impinged as three-year-olds, was about the same as the number impinged in 1975 and 1976. It thus appears that the 1974 year class was not small in comparison to the 1972 year class (impinged as three-year-olds in 1975) or the 1973 year-class (impinged as three-year-olds

Table 16. Estimates of conditional impingement mortality rates ( $m_I$ ) for the 1974 and 1975 striped bass year classes

Relative initial population size	Natural mortality	1974 Year class			1975 Year class		
		Initial population size ( $N_0$ )	Final population size <sup>a</sup>	Conditional impingement mortality rate ( $m_I$ )	Initial population size ( $N_0$ )	Final population size <sup>b</sup>	Conditional impingement mortality rate ( $m_I$ )
High	Low	$19.59 \times 10^6$	$5.01 \times 10^6$	0.011	$27.32 \times 10^6$	$7.03 \times 10^6$	0.004
High	High	$20.39 \times 10^6$	$2.31 \times 10^6$	0.018	$28.43 \times 10^6$	$3.26 \times 10^6$	0.007
Low	Low	$3.92 \times 10^6$	$0.96 \times 10^6$	0.056	$5.46 \times 10^6$	$1.38 \times 10^6$	0.021
Low	High	$4.08 \times 10^6$	$0.43 \times 10^6$	0.092	$5.69 \times 10^6$	$0.63 \times 10^6$	0.035

<sup>a</sup>Number of surviving two-year-olds on July 1, 1976.

<sup>b</sup>Number of surviving two-year-olds on July 1, 1977.

Table 17. Numbers of three-year-old alewives impinged at Hudson River power plants during April, May, and June, 1975 through 1977

Month	Year		
	1975	1976	1977
April	2205	2469	1380
May	8362	8289	9216
June	596	1558	897

in 1976). If the 1974 year class was not unusually weak, then an estimated number of surviving three-year-olds of 40,000 to 300,000 is not consistent with a spawning stock size of one million or more.

Since the early juvenile (July-October) mortality rate derived empirically for alewife ( $D = 0.0140$ ) was high in comparison to those derived for blueback herring ( $D = 0.0098$ ) and American shad ( $D = 0.0091$  for 1974 and  $D = 0.0131$  for 1975), model runs using three alternative, lower mortality rates were performed. First, we used the early juvenile mortality rate derived for blueback herring ( $D = 0.0098$ ). Second, we assumed that early juvenile mortality of alewives is equal to the mortality rate used for the months of November-May of the first year of vulnerability ( $D = 0.0044$ ). Third, we assumed that mortality during the entire period of vulnerability is equal to the mortality rate used for yearling and older fish ( $D = 0.0019$ ). These particular values were selected primarily for the sake of convenience. However, it is unlikely that the actual mortality of juvenile alewives is lower than the lowest value we used (i.e.,  $D = 0.0019$ ), since we have no reason to believe that the mortality of these fish is lower than that of juvenile striped bass. In combination with the minimum alewife initial abundance estimate of 4 million, all three of these mortality rates produced estimates of three-year-old abundance of less than 500,000. In combination with the maximum initial abundance estimate of 20 million, these three mortality rates produced estimates of three-year-old abundance ranging from 530,000 to 2.5 million. Results of all model runs are presented in Table 18.

We have chosen a three-year-old population size of 500,000, or about one-half the estimated minimum abundance of alewife spawners, as a cutoff point below which model output is considered to be unrealistic. Only the three runs that produced estimates of three-year-old abundance in excess of 500,000 were used to derive the range of estimates presented in Section 4 (Table 23). Clearly, estimates of the impact of impingement on this species are far less certain than are those for white perch and striped bass.

### 3.4 BLUEBACK HERRING

Like alewives, blueback herring are vulnerable to impingement until they are three years old. Moreover, the same types of data and analytical methods used to derive estimates of alewife abundance and mortality were also used for blueback herring. For these reasons estimates of the impact of impingement on blueback herring may be subject to the same kinds of problems encountered in estimating  $m_1$  for alewife. We therefore performed the same kinds of model runs for blueback herring that we did for alewife. We first used the empirically derived estimates developed in Appendix B. We then performed runs assuming that natural mortality is constant ( $D = 0.0044$ ) throughout the first eleven months of vulnerability (July 1-May 31). Finally, we performed runs assuming that the daily natural mortality rate is constant ( $D = 0.0019$ ) throughout the entire period of vulnerability to impingement.

Table 18. Estimates of conditional impingement mortality rates ( $m_I$ ) for the 1974 alewife year class

Relative initial population size	Natural mortality	Initial population size ( $N_0$ )	Final population size <sup>a</sup>	Conditional impingement mortality rate ( $m_I$ )
High	Low	$20.0 \times 10^6$	$2.48 \times 10^6$	0.014
High	Intermediate	$20.0 \times 10^6$	$1.05 \times 10^6$	0.024
High	High	$20.0 \times 10^6$	$0.53 \times 10^6$	0.043
High	Highest	$20.0 \times 10^6$	$0.31 \times 10^6$	0.068 <sup>b</sup>
Low	Low	$4.0 \times 10^6$	$0.47 \times 10^6$	0.069 <sup>b</sup>
Low	Intermediate	$4.0 \times 10^6$	$0.19 \times 10^6$	0.118 <sup>b</sup>
Low	High	$4.0 \times 10^6$	$0.09 \times 10^6$	0.213 <sup>b</sup>
Low	Highest	$4.0 \times 10^6$	$0.04 \times 10^6$	0.340 <sup>b</sup>

<sup>a</sup>Number of surviving three-year-olds on July 1, 1977.

<sup>b</sup>Excluded from maximum range of conditional impingement mortality rates because of unrealistically low estimate of final population size.

The Hudson river blueback herring population is considerably larger than the alewife population. According to Exhibit UT-4 (p. 6.47) juvenile blueback herring were 55 times as abundant as juvenile alewives in August-November of 1975. The population estimates developed in Appendix B do not support a disparity that large, but they do indicate a substantial difference: 29 to 145 million blueback herring vs 4 to 20 million alewives, i.e., a ratio of about 7 to 1. In order to compute a minimum acceptable three-year-old abundance estimate for blueback herring analogous to that derived for alewife, we simply multiplied the alewife acceptance criterion (500,000) by seven. Values of  $m_T$  for blueback herring obtained from model runs that produced estimates of three-year-old abundance smaller than 3.5 million fish were excluded when the maximum range of estimates for this species was compiled (Section 4, Table 23). All of the estimates are presented in Table 19. Like the results obtained for alewife, the range of maximum and minimum estimates of  $m_T$  for blueback herring is much less certain than those obtained for white perch and striped bass.

### 3.5 AMERICAN SHAD

Only two model runs were performed for each of the two American shad year classes (1974 and 1975) considered in this testimony. Even though the empirically derived estimates of early juvenile mortality for this species are nearly as high as those derived for alewife and blueback herring, the highest estimates of  $m_T$  obtained were no higher than about 0.01. It was, therefore, not thought worthwhile to perform model runs using lower natural mortality rates, as was done for alewife and blueback herring. The results of the model runs for American shad are presented in Table 20.

### 3.6 ATLANTIC TOMCOD

Table 21 contains the results of six model runs for Atlantic tomcod, two for the 1974 year class and four for the 1975 year class. Estimates of  $m_T$  for the 1974 year class were obtained using the daily mortality rate and maximum and minimum initial population sizes derived directly from TI's 1974 Long River Survey data (Appendix B). The estimated numbers of Atlantic tomcod surviving on February 1, 1975 (3.3 to 17 million) were reasonably consistent with, although somewhat higher than, the estimate of Atlantic tomcod spawning stock size during the winter of 1974-1975 (Table 14) obtained from TI's mark/recapture program (2.47 million).

When similar runs were performed for the 1975 year class using the daily mortality rate and maximum and minimum population sizes derived from TI's 1975 Long River Survey data, unrealistically low estimates of the number of fish surviving to the end of the spawning season were obtained. According to the model results, between 130,000 (minimum initial population) and 700,000 (maximum initial population) members of the 1975 year class were alive on February 1, 1976. However, results obtained from TI's mark/recapture program (Table 14) indicate a winter population size of about

Table 19. Estimates of conditional impingement mortality rates ( $m_I$ ) for the 1974 blueback herring year class

Relative initial population size	Natural mortality	Initial population size ( $N_0$ )	Final population size <sup>a</sup>	Conditional impingement mortality rate ( $m_I$ )
High	Low	$145.0 \times 10^6$	$18.14 \times 10^6$	0.005
High	Intermediate	$145.0 \times 10^6$	$7.77 \times 10^6$	0.008
High	High	$145.0 \times 10^6$	$3.98 \times 10^6$	0.015
Low	Low	$29.0 \times 10^6$	$3.56 \times 10^6$	0.025
Low	Intermediate	$29.0 \times 10^6$	$1.50 \times 10^6$	0.040 <sup>b</sup>
Low	High	$29.0 \times 10^6$	$0.75 \times 10^6$	0.075 <sup>b</sup>

<sup>a</sup>Number of surviving three-year-olds on July 1, 1977.

<sup>b</sup>Excluded from maximum range of conditional impingement mortality rates because of unrealistically low estimate of final population size.

Table 20. Estimates of conditional impingement mortality rates ( $m_I$ ) for the 1974 and 1975 American shad year classes

Relative initial population size	1974 Year class			1975 Year class		
	Initial population size ( $N_0$ )	Final population size <sup>a</sup>	Conditional impingement mortality rate ( $m_I$ )	Initial population size ( $N_0$ )	Final population size <sup>b</sup>	Conditional impingement mortality rate ( $m_I$ )
High	$78.0 \times 10^6$	$8.69 \times 10^6$	0.001	$80.0 \times 10^6$	$5.11 \times 10^6$	0.002
Low	$15.6 \times 10^6$	$1.73 \times 10^6$	0.005	$16.0 \times 10^6$	$1.01 \times 10^6$	0.011

<sup>a</sup>Number of yearlings alive on June 1, 1975.

<sup>b</sup>Number of yearlings alive on June 1, 1976.

Table 21. Estimates of conditional impingement mortality rates ( $m_I$ ) for the 1974 and 1975 Atlantic tomcod year classes

Relative initial population size	Natural mortality <sup>a</sup>	1974 Year class			1975 Year class		
		Initial population size ( $N_0$ )	Final population size <sup>b</sup>	Conditional impingement mortality rate ( $m_I$ )	Initial population size ( $N_0$ )	Final population size <sup>c</sup>	Conditional impingement mortality rate ( $m_I$ )
High	Low	999.0x10 <sup>6</sup>	17.0x10 <sup>6</sup>	0.010	433.5x10 <sup>6</sup>	7.4 x10 <sup>6</sup>	0.006
High	High	--	--	--	433.5x10 <sup>6</sup>	0.70x10 <sup>6</sup>	0.025 <sup>d</sup>
Low	Low	199.8x10 <sup>6</sup>	3.26x10 <sup>6</sup>	0.049	86.7x10 <sup>6</sup>	1.4 x10 <sup>6</sup>	0.030
Low	High	--	--	--	86.7x10 <sup>6</sup>	1.3 x10 <sup>5</sup> or 0.13x10 <sup>6</sup>	0.123 <sup>d</sup>

<sup>a</sup>Low natural mortality rate derived from TI's 1974 Long River Survey data; high natural mortality rate derived from TI's 1975 Long River survey data.

<sup>b</sup>Number of spawners (yearlings) alive on February 1, 1975.

<sup>c</sup>Number of spawners (yearlings) alive on February 1, 1976.

<sup>d</sup>Excluded from maximum range of conditional impingement mortality rates because of unrealistically low estimate of final population size.

3.5 million. Since the daily mortality rate computed from the 1975 Long River Survey data was unusually high ( $D = 0.0244$ ), we performed another two runs using the lower mortality rate ( $D = 0.0155$ ) derived from the 1974 data. These runs produced estimates of spawning stock size during the winter of 1975-76 that are in reasonable agreement with the mark/recapture population estimates. The projected January 31 population sizes obtained from the model runs ranged from 1.4 million to 7.4 million, or about one half to two times the mark/recapture estimate (3.51 million). The results of these two runs, rather than the two that employed the higher natural mortality rate, are presented in Table 23. Similar results could have been obtained by applying the empirically derived mortality rate for 1975 ( $D = 0.0244$ ) over the spring and summer and applying a lower rate (e.g.,  $D = 0.0044$ ) over the remainder of the period of vulnerability.

### 3.7 BAY ANCHOVY

For reasons discussed in Section 1, we made no attempts to compute conditional impingement mortality rates for bay anchovy. Instead, exploitation rates for the total impingeable population (adults + juveniles) residing above RM 12 were computed for the months of May through October. These rates are presented in Table 22.

Table 22. Estimates of bay anchovy<sup>a</sup> exploitation rates for the months of May through October, 1974 and 1975

Month	1974		1975	
	High abundance	Low abundance	High abundance	Low abundance
May	$1.3 \times 10^{-5}$	$6.3 \times 10^{-5}$	$1.5 \times 10^{-6}$	$7.7 \times 10^{-6}$
June	0.0008	0.0040	0.0004	0.0020
July	0.0072	0.0361	0.0073	0.0367
August	0.0017	0.0085	0.0037	0.0184
September	0.0017	0.0086	0.0014	0.0068
October	0.0007	0.0036	0.0017	0.0084

<sup>a</sup>Adults + juveniles.

## 4. DISCUSSION

The ranges of conditional impingement mortality rates computed for white perch, striped bass, alewife, blueback herring, American shad, and Atlantic tomcod are summarized in Table 23. Because more and better field data are available for white perch and striped bass than for the other species considered in this testimony, impact estimates for these two species (especially for white perch) are more certain than are those for alewife, blueback herring, American shad, and Atlantic tomcod. The least adequate data are available for alewife and blueback herring, and consequently the impact estimates for these two species are the least certain. We included them in our analysis because we felt that the decision-maker should be provided with some perspective, however rough, as to the impact of impingement on these two species.

The purpose of this discussion is to compare our results to those presented in Sections 2-VI and 2-VII of Exhibit UT-3. For reasons discussed in Section 1.1, no comparison with the LMS "impingement cropping estimates" contained in Sections 10.4 of Exhibits UT-6 and UT-7 is possible or appropriate. Comparisons between our work and that of the utilities are possible for four species: white perch, striped bass, Atlantic tomcod, and American shad. For convenience, the estimates of  $m_I$  computed by the utilities are listed in Table 23 along with our own. With the exception of white perch, the two sets of estimates are in fairly good agreement, in spite of the differences in input data and analytical methodology.

The utilities' estimates of the impact of impingement on the 1974 and 1975 striped bass year classes and on the 1974 Atlantic tomcod year class fall between our maximum and minimum estimates. For both striped bass year classes they fall nearly at the midpoint of our range. Our estimates of  $m_I$  for the 1974 American shad year class are considerably lower than that of the utilities. The reason for this is the large difference in the estimates of the initial number of impingeable juvenile shad. The utilities' estimate of  $N_0$  can be computed from the exploitation rate (0.0058) and total impingement count (10,602) presented in Table 2-VII-3 of Exhibit UT-3; it is 1.8 million fish. This value was obtained from the same beach seine data we used, but it is an estimate only of the number of juveniles present in the shorezone (Exhibit UT-4, p. 14.17). Since the American shad is a pelagic fish, it is likely that the shorezone contains a relatively small fraction of the total population. We believe that our own estimates of the abundance of juvenile shad are more realistic than is that of the utilities.

The most striking disagreement between our results and those of the utilities is in our assessment of the impact of impingement on white perch. The utilities' estimate of  $m_I$  for the 1974 year class (they present no estimate for the 1975 year class) is at the lower end of our maximum range of estimates and falls outside our range of probable estimates. This difference is especially surprising in view of the similarity of our data bases. The utilities estimated that 2,045,385 white perch belonging to the

Table 23. Ranges of estimates of conditional impingement mortality rates ( $m_I$ ) for six Hudson River fish species

Species (year class)	Low estimate	High estimate	Utilities' estimate
White perch (1974)			
Maximum range	0.095	0.588	
Probable range	0.119	0.446	0.113 <sup>a</sup>
White perch (1975)			
Maximum range	0.077	0.245	
Probable range	0.115	0.245	--
Striped bass (1974)	0.011	0.092	0.042 <sup>b</sup>
Striped bass (1975)	0.004	0.035	0.023 <sup>b</sup>
Alewife (1974)	0.014	0.043	--
Blueback herring (1974)	0.005	0.025	--
American shad (1974)	0.001	0.005	0.012 <sup>c</sup>
American shad (1975)	0.002	0.011	--
Atlantic tomcod (1974)	0.010	0.049	0.015 <sup>d</sup>
Atlantic tomcod (1975)	0.006	0.030	--

<sup>a</sup>From Exhibit UT-3, Table 2-VII-1.

<sup>b</sup>From Exhibit UT-3, Table 2-VI-2.

<sup>c</sup>From Exhibit UT-3, Table 2-VII-3.

<sup>d</sup>From Exhibit UT-3, Table 2-VII-2.

1974 year class were impinged between July 1, 1974 and June 30, 1975 (Exhibit UT-3, Table 2-VII-1). We estimate, by adding up the monthly impingement counts in Table 2, that 2.8 to 2.9 million white perch belonging to the 1974 year class were impinged during 2 to 3 years of vulnerability. The lower limit of our range of probable impacts was computed using a higher estimate of fall abundance (39 million vs 21 million) and a lower estimate of young-of-the-year mortality ( $D = 0.0019$  vs  $D = 0.0044$ ). As was noted in Section 3.1, if all other factors were equal, these two differences would result in our estimate of  $m_I$  being considerably lower than that of the utilities. However, in spite of these two differences, our minimum probable estimate of  $m_I$  is higher than the utilities' estimate.

Although our higher impingement total explains part of the discrepancy, the major reasons why our estimates of  $m_I$  for white perch are so much higher than that of the utilities are:

- (1) The utilities assume that the vulnerability of fish to impingement does not vary seasonally.
- (2) The utilities end the period of vulnerability at one year.

The value of a juvenile fish to the population increases with its age because its probability of surviving to adulthood increases. For this reason, the impact to the population of killing any particular juvenile increases with its age. Tables 2 and 3 clearly show that, although young-of-the-year white perch become vulnerable to impingement in July, relatively few are impinged before October. The greatest impingement occurs between December and April. Over 600,000 white perch belonging to the 1974 year class were impinged in April, 1975, when they were nearly one year old. Even if the period of vulnerability were limited to one year, the utilities' estimate of  $m_I$  for the 1974 white perch year class would underestimate the true impact because most of the impingement occurred toward the end of that period, when the impact of killing each fish is higher (Barnthouse et al. 1979).

The impact of killing a yearling or two-year-old white perch is even higher. If, as the utilities assume, the total mortality of juvenile white perch between July of the year they are spawned and July of the following year is 80%, then a single yearling impinged in July is worth five juveniles impinged 12 months earlier. If mortality between age 1 and age 2 is 50% (i.e.,  $D = 0.0019$ , the daily mortality rate we used for this period), then each 2-year-old white perch is worth two yearlings or ten young-of-the-year. Even though the number of yearling and older white perch impinged each year constitutes only about 10% of total white perch impingement, the impact of killing these fish is quite substantial. In our opinion the utilities have seriously underestimated the impact of impingement on the 1974 white perch year class by failing to account for the impingement of yearling and older fish.

## 5. REDUCTIONS IN IMPACT DUE TO THE INSTALLATION OF CLOSED-CYCLE COOLING SYSTEMS

This section provides the decision-maker with quantitative estimates of the ecological benefits to be gained by the installation of closed-cycle cooling systems at Bowline, Indian Point Units 2 and 3, and Roseton. We have computed estimates of the reduced impact that would have been imposed on the 1974 and 1975 year classes of white perch, striped bass, and Atlantic tomcod had closed-cycle cooling systems been operating at one or more of the three plants at issue in these proceedings. We considered three closed-cycle cooling configurations: (1) cooling towers at all three plants, (2) cooling towers at Bowline and Indian Point and once-through cooling at Roseton, and (3) cooling towers at Indian Point and once-through cooling at Bowline and Roseton.

The numbers of white perch, striped bass, and Atlantic tomcod that would have been impinged, had closed-cycle cooling systems been in operation during the years 1974-77, were calculated by assuming that the number of fish impinged at a particular plant is directly proportional to the volume of cooling water withdrawn by that plant. A detailed description of the method used to estimate the numbers of fish impinged during each month, given each closed-cycle cooling configuration, is contained in Appendix C.

The estimates of abundance and mortality used to estimate the impact of impingement assuming closed-cycle cooling were the same ones used to generate the ranges of estimates of  $m_I$  presented in Table 23. Thus, except for the impingement data, the input data used to generate estimates of  $m_I$  assuming closed-cycle cooling were identical to those used to compute minimum and maximum estimates of  $m_I$  for once-through cooling systems at all plants. Ranges of conditional impingement mortality rates for the 1974 and 1975 year classes of white perch, striped bass, and Atlantic tomcod, for all three closed-cycle configurations, are presented in Table 24.

Comparison of Tables 23 and 24 shows that the installation of closed-cycle cooling would have greatly reduced the impact of impingement on all three species. If cooling towers had existed at all three plants (Configuration 1), the maximum conditional impingement mortality rates for white perch would have been reduced from 0.588 to 0.150 for the 1974 year class and from 0.245 to 0.042 for the 1975 year class. The maximum values of  $m_I$  for striped bass would have been reduced from 0.092 to 0.023 for the 1974 year class and from 0.035 to 0.013 for the 1975 year class. For Atlantic tomcod, the maximum impacts would have been reduced from 0.049 to 0.018 for the 1974 year class and from 0.030 to 0.003 for the 1975 year class.

Similar reductions could have been obtained given closed-cycle cooling at Bowline and Indian Point only (Configuration 2). The ranges of  $m_I$  for striped bass and Atlantic tomcod, assuming once-through cooling at Roseton, are virtually identical to those obtained assuming closed-cycle cooling at

Table 24. Estimates of  $m_I$  for the 1974 and 1975 year classes of white perch, striped bass, and Atlantic tomcod, assuming three alternative close-cycle cooling configurations

	Configuration					
	1 <sup>a</sup>		2 <sup>b</sup>		3 <sup>c</sup>	
	Low	High	Low	High	Low	High
White perch (1974)						
Maximum range	0.027	0.150	0.030	0.177	0.042	0.237
Probable range	0.031	0.128	0.036	0.143	0.049	0.195
White perch (1975)						
Maximum range	0.013	0.042	0.019	0.061	0.024	0.078
Probable range	0.020	0.042	0.029	0.061	0.036	0.078
Striped bass (1974)	0.003	0.023	0.003	0.024	0.010	0.081
Striped bass (1975)	0.001	0.013	0.001	0.013	0.003	0.024
Atlantic tomcod (1974)	0.004	0.018	0.004	0.019	0.004	0.019
Atlantic tomcod (1975)	0.001	0.003	0.001	0.004	0.001	0.004

<sup>a</sup>Closed-cycle cooling at Bowline, Indian Point, and Roseton.

<sup>b</sup>Closed-cycle cooling at Bowline and Indian Point; once-through cooling at Roseton.

<sup>c</sup>Closed-cycle cooling at Indian Point; once-through cooling at Bowling and Roseton.

all three plants. Only for the 1975 white perch year class were appreciably higher values of  $m_I$  obtained assuming Configuration 2 than assuming Configuration 1.

Results obtained assuming Configuration 3 indicate that the installation of closed-cycle cooling at Indian Point Units 2 and 3 alone would have resulted in substantial reductions in the impact of impingement on white perch and Atlantic tomcod. The maximum and minimum values of  $m_I$  for both white perch year classes would have been reduced by more than 50% if closed-cycle cooling had been installed at Indian Point alone. Similar reductions in the impact of impingement on the 1974 Atlantic tomcod year class would have resulted. A reduction in impact of more than 80% would have been obtained for the 1975 Atlantic tomcod year class. For Atlantic tomcod, the installation of cooling towers at Bowline and Roseton would have resulted in very little additional reduction in impact.

For striped bass, the reductions in impact that would have resulted from the installation of cooling towers at Indian Point alone would have been smaller than for the other two species. This result is not surprising, since it is winter impingement at Bowline (Exhibit UT-4, Table 9.2-9) that has been responsible for the greatest impingement impact on this population. Table 24 indicates that the installation of closed-cycle cooling at both Indian Point and Bowline would have reduced the impact of impingement on striped bass by a factor of 2-4 in comparison to closed-cycle cooling at Indian Point alone.

Since future operating conditions at Lovett, Danskammer, and Indian Point Unit 3 will differ from those that prevailed during 1974 and 1975, our results are not projections of future impacts given closed-cycle cooling. In the future, generating loads and cooling water withdrawals at Lovett and Danskammer will be reduced. Consequently, the impacts of impingement at these two plants on future year classes of white perch, striped bass, and Atlantic tomcod (and other species as well) will be reduced in comparison to the impacts imposed on the 1974 and 1975 year classes. These reductions in impact will be offset by increased impacts due to impingement at Indian Point Unit 3, which did not begin commercial operation until 1976. Neither the impact of once-through cooling at Indian Point Unit 3 nor the reductions in impact resulting from the installation of cooling towers at Indian Point are fully reflected in the results presented in Tables 23 and 24. Because our results underestimate the contribution of Indian Point Unit 3 to future riverwide impingement totals, they probably underestimate the reductions in impact that would be obtained from the installation of closed-cycle cooling systems at one or more of the three plants that are the subject of these proceedings.

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## APPENDIX A

## NUMBER OF FISH IMPINGED BY SPECIES, POWER STATION, AND MONTH

The purpose of this appendix is to document the source of the impingement numbers in Tables 2-13. The appendix is organized by species and by power station within species. The six species considered in this appendix (in order) are striped bass, blueback herring, alewife, American shad, Atlantic tomcod, and bay anchovy. The six power stations considered (in order, moving upriver) are Bowline Point, Lovett, Indian Point, Roseton, Danskammer, and Albany.

For each species except bay anchovy, tabulations start in 1974 with the first month when young-of-the-year of the 1974 year class of each species were impinged. For bay anchovy tabulations start in May 1974 with appearance of spawners in impingement collections. Tabulations end in 1976 with April for Atlantic tomcod and with May for American shad, resulting in 24 monthly estimates of number of fish impinged. For these two species essentially only young-of-the-year are impinged, so the 24 monthly estimates allow for calculation of the conditional impingement mortality rate for the 1974 year class and the 1975 year class.

An exploitation rate over a specified period of time, rather than a conditional impingement mortality rate for a given year class, is calculated for bay anchovy, for reasons discussed in Section 1. Tabulations for bay anchovy end with June 1976 before impingement sharply increases due to young-of-the-year in the 1976 year class reaching impingeable size.

Striped bass are impinged as young-of-the-year and as yearlings, while blueback herring and alewife are impinged as young-of-the-year, yearlings (before they migrate to the ocean), and three-year olds and older when they return to the Hudson to spawn. Thus, for these three species it was necessary to estimate on a monthly basis at each power station the fraction of the fish impinged that were of each age. For striped bass the tabulation is from July 1974 through June 1977, which allows for calculation of the conditional impingement mortality rate for the 1974 year class and the 1975 year class. Tabulations for blueback herring and alewife are for the same period, but because of the need to include impingement of three-year olds, it is possible to calculate a conditional impingement mortality rate for only the 1974 year class.

## STRIPED BASS

Bowline

Number collected: values taken directly from data sheets in Ref. (10) for July 1974 - December 1976 and from data sheets in Ref. (13) for January 1977 - June 1977.

FAO (fraction collected in age class 0): January 1975 - December 1976: calculated from monthly length-frequency distributions [Tables 10.2-18 and 10.2-19 in Ref. (1)]. The "DIVISION" criteria specified by Texas Instruments were used as the cut-off length between young-of-the-year and yearling striped bass (see Table A1 in this appendix).

July 1974 - December 1974 and January 1977 - June 1977: in the absence of monthly values during these periods, estimates were calculated as the average of the 1975 and 1976 FAO values for each month.

Lovett

Number collected: same sources as for Bowline.

FAO (fraction collected in age class 0): No estimates of FAO were available for Lovett. Consequently, all monthly values for FAO were approximated based on data from Indian Point, which is located only 1½ miles upriver and across the river from Lovett.

Indian Point

Number collected: July 1974 - December 1976: Copied directly from appendix tables in Refs. (5) - (8). However, if a value in these Texas Instruments (TI) appendix tables was lower than the corresponding value on the data sheets in Refs. (10) and (12), then the updated value in Refs. (10) and (12) was used. In general, the values presented in the TI appendix tables are the same as or higher than the values presented in Refs. (10) and (12) for the reason discussed by Con Edison in their response to Question VI.2 in Ref. (10). Thus, the substituted higher values from Refs. (10) and (12) can still be low, because they were selected by TI to include only data that represented known flow volumes and associated impingement collections.

January 1977 - June 1977: Copied directly from data sheets provided in Refs. (14) and (15).

FAO (fraction collected in age class 0): June 1975 - December 1976: Calculated from data on magnetic tapes provided by Consolidated Edison. The two tapes used were Texas Instruments 1975 Impingement Data (Record Type D) and Texas Instruments 1976 Impingement Data (Record Type D). Monthly estimates of FAO were calculated for each unit for which there were striped bass impingement data as follows:

$$\text{FAO} = \frac{\text{Number of impinged striped bass in Length Class 1}}{\text{Total number of impinged striped bass}},$$

where the bounds on Length Class 1 are 0 mm to DIVISION, where DIVISION is the seasonally-varying, total body length in millimeters which is used as the cut-off length between young-of-the-year and yearling striped bass (see Table A1 of this appendix).

July 1974 - May 1975 and January 1977 - June 1977: in the absence of monthly values during these two periods, estimates were calculated using the June 1975 - December 1976 values.

#### Roseton

Number collected: July 1974 - December 1976: copied directly from Table 10.2-9 of Ref. (2). January 1977 - June 1977: calculated from the monthly average collection rates in Ref. (11) and monthly values of actual total plant intake flow in millions of gallons for the particular month (from data sheets provided by U. S. Environmental Protection Agency, Region II, New York, New York).

FAO (fraction collected in age class 0): same methodology as for Bowline, except based on Tables 10.2-19 and 10.2-20 in Ref. (2).

#### Danskammer

Number collected: July 1974 - June 1977: calculated from the monthly average collection rates in Refs. (10) and (11) and monthly values of actual total plant intake flow in millions of gallons for the particular month, from data sheets in Ref. (9) for July 1974 - December 1976 and from data sheets provided by the U. S. Environmental Protection Agency, Region II, New York, New York for January-June 1977.

FAO (fraction collected in age class 0): no estimates of FAO were available for Danskammer. Consequently, all monthly values for FAO were approximated based on data from Roseton, which is adjacent to Danskammer.

Albany

Number collected: July 1974 - March 1975 (Ref. 3): calculated from monthly data on estimated number of fish of all species collected at all units (from Table 2, Column D, Total) and monthly data on percentage composition by species of the fish collected (from Table 4).

April 1975 - March 1976 (Ref. 4): calculated from monthly data on average observed number of fish of all species collected per million gallons of intake flow at all units (from Table IVC-16), monthly data on percentage composition by species of the fish collected (from Table IVC-14), and monthly values of average daily plant flow for all units in millions of gallons per day times the number of days in the particular month (from Table IVC-16).

April 1976 - June 1977: in the absence of monthly values during this period, estimates were calculated for each month as the average of the two values for that particular month within the period July 1974 - March 1976.

FAO (fraction collected in age class 0): July 1974 - March 1975 (Ref. 3): estimated from the monthly plots in Fig. 10 of frequency versus length intervals of striped bass collected at the Albany Steam Electric Generating Station. The "DIVISION" criteria specified by Texas Instruments were used as the cut-off length between young-of-the-year and yearling striped bass (see Table A1 in this appendix).

April 1975 - March 1976 (Ref. 4): estimated from the plots in Fig. IVC-5 of relative frequency versus length intervals of striped bass collected at the Albany Steam Electric Generating Station. The "DIVISION" criteria specified by Texas Instruments were used as the cut-off point between young-of-the-year and yearling striped bass (see Table A1 in this appendix).

April 1976 - June 1977: in the absence of monthly values during this period, estimates were calculated for each month as the average of the two values for that particular month within the period July 1974 - March 1976.

## BLUEBACK HERRING

Bowline

Number collected: copied directly from data sheets in Ref. (10) for July 1974 - December 1976 and from data sheets in Ref. (13) for January 1977 - June 1977.

FAO (fraction collected in age class 0): January 1975 - December 1976: calculated from monthly length-frequency distributions [Tables 10.2-27 and 10.2-28 in Ref. (1)]. The seasonally varying, total body length used to discriminate between young-of-the-year and yearling blueback herring was estimated from these length-frequency distributions.

July 1974 - December 1974 and January 1977 - June 1977: in the absence of monthly values during these two periods, estimates were calculated as the average of the 1975 and 1976 FAO values for each month.

Lovett

Number collected: same sources as for Bowline.

FAO (fraction collected in age class 0): No estimates of FAO were available for Lovett. In addition, no values were available for Indian Point. Consequently, values from Bowline were used.

Indian Point

Number collected: July 1974 - December 1976: Copied directly from appendix tables in Refs. (5) - (8). However, if a value in these Texas Instruments (TI) appendix tables was lower than the corresponding value on the data sheets in Refs. (10) and (12), then the value in Refs. (10) and (12) was used. In general, the values presented in the TI appendix tables are the same as or higher than the values presented in Refs. (10) and (12) for the reason discussed by Con Edison in their response to Question VI.2 in Ref. (10). Thus, the substituted higher values from Refs. (10) and (12) can still be low, because they were selected by TI to include only data that represented known flow volumes and associated impingement collections.

January 1977 - June 1977: Copied directly from data sheets provided in Refs. (14) and (15).

FAO (fraction collected in age class 0): No estimates of FAO were available for Indian Point. Consequently, values from Bowline, which is the power plant closest to Indian Point for which FAO values were available, were used.

Roseton

Number collected: July 1974 - December 1976: copied directly from Table 10.2-9 of Ref. (2). January 1977 - June 1977: calculated from the monthly average collection rates in Ref. (11) and monthly values of actual total plant intake flow in millions of gallons for the particular month (from data sheets provided by U. S. Environmental Protection Agency, Region II, New York, New York).

FAO (fraction collected in age class 0): same methodology as for Bowline, except based on Tables 10.2-29 and 10.2-30 in Ref. (2).

Danskammer

Number collected: July 1974 - June 1977: calculated from the monthly average collection rates in Refs. (10) and (11) and monthly values of actual total plant intake flow in millions of gallons for the particular month, from data sheets in Ref. (9) for July 1974 - December 1976 and from data sheets provided by U. S. Environmental Protection Agency, Region II, New York, New York for January-June 1977.

FAO (fraction collected in age class 0): no estimates of FAO were available for Danskammer. Consequently, all monthly values for FAO were approximated based on data from Roseton, which is adjacent to Danskammer.

Albany

Number collected: July 1974 - March 1975 (Ref. 3): calculated from monthly data on estimated number of fish of all species collected at all units (from Table 2, Column D, Total) and monthly data on percentage composition by species of the fish collected (from Table 4).

April 1975 - March 1976 (Ref. 4): calculated from monthly data on average observed number of fish of all species collected per million gallons of intake flow at all units (from Table IVC-16), monthly data on percentage composition by species of the fish collected (from Table IVC-14), and monthly values of average daily plant flow for all units in millions of gallons per day times the number of days in the particular month (from Table IVC-16).

April 1976 - June 1977: in the absence of monthly values during this period, estimates were calculated for each month as the average of the two values for that particular month within the period July 1974 - March 1976.

FAO (fraction collected in age class 0): estimated from the monthly plots in Fig. 7 of Ref. (3) of frequency versus length intervals of blueback herring collected at the Albany Steam Electric Generating Station.

## ALEWIFE

Bowline

Number collected: copied directly from data sheets in Ref. (10) for July 1974 - December 1976 and from data sheets in Ref. (13) for January 1977 - June 1977.

FAO (fraction collected in age class 0): January 1975 - December 1976: calculated from monthly length-frequency distributions [Tables 10.2-24 and 10.2-25 in Ref. (1)]. The seasonally varying, total body length used to discriminate between young-of-the-year and yearling alewife herring was estimated from these length-frequency distributions.

July 1974 - December 1974 and January 1977 - June 1977: in the absence of monthly values during these two periods, estimates were calculated as the average of the 1975 and 1976 FAO values for each month.

Lovett

Number collected: same sources as for Bowline.

FAO (fraction collected in age class 0): No estimates of FAO were available for Lovett. In addition, no values were available for Indian Point. Consequently, values from Bowline were used.

Indian Point

Number collected: July 1974 - December 1976: Copied directly from appendix tables in Refs. (5) - (8). However, if a value in these Texas Instruments (TI) appendix tables was lower than the corresponding value on the data sheets for Indian Point in Refs. (10) and (12), then the value in Refs. (10) and (12) was used. In general, the values presented in the TI appendix tables are the same as or higher than the values presented in Refs. (10) and (12) for the reason discussed by Con Edison in their response to Question VI.2 in Ref. (10). Thus, the substituted higher values from Refs. (10) and (12) can still be low, because they were selected by TI to include only data that represented known flow volumes and associated impingement collections.

January 1977 - June 1977: Copied directly from data sheets provided in Refs. (14) and (15).

FAO (fraction collected in age class 0): No estimates of FAO were available for Indian Point. Consequently, values from Bowline, which is the power plant closest to Indian Point for which FAO values were available, were used.

Roseton

Number collected: July 1974 - December 1976: copied directly from Table 10.2-25 of Ref. (2). January 1977 - June 1977: calculated from the monthly average collection rates in Ref. (11) and monthly values of actual total plant intake flow in millions of gallons for the particular month (from data sheets provided by U. S. Environmental Protection Agency, Region II, New York, New York).

FAO (fraction collected in age class 0): same methodology as for Bowline, except based on Tables 10.2-26 and 10.2-27 in Ref. (2).

Danskammer

Number collected: July 1974 - June 1977: calculated from the monthly average collection rates in Refs. (10) and (11) and monthly values of actual total plant intake flow in millions of gallons for the particular month, from data sheets in Ref. (9) for July 1974 - December 1976 and from data sheets provided by U. S. Environmental Protection Agency, Region II, New York, New York for January-June 1977.

FAO (fraction collected in age class 0): no estimates of FAO were available for Danskammer. Consequently, all monthly values for FAO were approximated based on data from Roseton, which is adjacent to Danskammer.

Albany

Number collected: July 1974 - March 1975 (Ref. 3): calculated from monthly data on estimated number of fish of all species collected at all units (from Table 2, Column D, Total) and monthly data on percentage composition by species of the fish collected (from Table 4).

April 1975 - March 1976 (Ref. 4): calculated from monthly data on average observed number of fish of all species collected per million gallons of intake flow at all units (from Table IVC-16), monthly data on percentage composition by species of the fish collected (from Table IVC-14), and monthly values of average daily plant flow for all units in millions of gallons per day times the number of days in the particular month (from Table IVC-16).

April 1976 - June 1977: in the absence of monthly values during this period, estimates were calculated for each month as the average of the two values for that particular month within the period July 1974 - March 1976.

FAO (fraction collected in age class 0): estimated from the monthly plots in Fig. 7 of Ref. (3) of frequency versus length intervals of alewife collected at the Albany Steam Electric Generating Station.

## AMERICAN SHAD

Bowline

Number collected: copied directly from data sheets for Bowline in Ref. (10) for June 1974 - May 1976.

Lovett

Number collected: copied directly from data sheets for Lovett in Ref. (10) for June 1974 - May 1976.

Indian Point

Number collected: June 1974 - May 1976: Copied directly from appendix tables in Refs. (5) - (8). However, if a value in these Texas Instruments (TI) appendix tables was lower than the corresponding value on the data sheets in Refs. (10) and (12), then the value in Refs. (10) and (12) was used. In general, the values presented in the TI appendix tables are the same as or higher than the values presented in Refs. (10) and (12) for the reason for this is discussed by Con Edison in their response to Question VI.2 in Ref. (10). Thus, the substituted higher values from Refs. (10) and (12) can still be low, because they were selected by TI to include only data that represented known flow volumes and associated impingement collections.

Roseton and Danskammer

Number collected: copied directly from data sheets in Ref. (16).

Albany

Number collected: June 1974 - March 1975 (Ref. 3): calculated from monthly data on estimated number of fish of all species collected at all units (from Table 2, Column D, Total) and monthly data on percentage composition by species of the fish collected (from Table 4).

April 1975 - March 1976 (Ref. 4): calculated from monthly data on average observed number of fish of all species collected per million gallons of intake flow at all units (from Table IVC-16), monthly data on percentage composition by species of the fish collected (from Table IVC-14), and monthly values of average daily plant flow for all units in millions of gallons per day times the number of days in the particular month (from Table IVC-16).

April 1976 - May 1977: in the absence of monthly values during this period, estimates were calculated for each month as the average of the two values for that particular month within the period July 1974 - March 1976.

## ATLANTIC TOMCOD

Bowline

Number collected: values taken directly from data sheets for Bowline in Ref. (10) for May 1974 - April 1976.

Lovett

Number collected: values taken directly from data sheets for Lovett in Ref. (10) for May 1974 - April 1976.

Indian Point

Number collected: May 1974 - April 1976: Copied directly from appendix tables in Refs. (5) - (8). However, if a value in these Texas Instruments (TI) appendix tables was lower than the corresponding value on the data sheets in Refs. (10) and (12), then the value in Refs. (10) and (12) was used. In general, the values presented in the TI appendix tables are the same as or higher than the values presented in Refs. (10) and (12) for the reason discussed by Con Edison in their response to Question VI.2 in Ref. (10). Thus, the substituted higher values from Refs. (10) and (12) can still be low, because they were selected by TI to include only data that represented known flow volumes and associated impingement collections.

Roseton

Number collected: May 1974 - April 1976: copied directly from Table 10.2-10 of Ref. (2).

Danskammer

Number collected: May 1974 - April 1976: calculated from the monthly average collection rates in Ref. (10) and monthly values of actual total plant intake flow in millions of gallons for the particular month obtained from data sheets in Ref. (9).

Albany

Number collected: April 1974 - March 1975 (Ref. 3): calculated from monthly data on estimated number of fish of all species collected at all units (from Table 2, Column D, Total) and monthly data on percentage composition by species of the fish collected (from Table 4).

April 1975 - March 1976 (Ref. 4): calculated from monthly data on average observed number of fish of all species collected per million gallons of intake flow at all units (from Table IVC-16), monthly data on percentage composition by species of the fish collected (from Table IVC-14), and monthly values of average daily plant flow for all units in millions of gallons per day times the number of days in the particular month (from Table IVC-16).

April 1976 calculated as the average of the 1974 and 1975 values for April.

BAY ANCHOVY

Bowline

Number collected: copied directly from data sheets for Bowline in Ref. (10) for May 1974 - June 1976.

Lovett

Number collected: copied directly from data sheets for Lovett in Ref. (10) for May 1974 - June 1976.

Indian Point

Number collected: May 1974 - June 1976: Copied directly from appendix tables in Refs. (5) - (8). However, if a value in these Texas Instruments (TI) appendix tables was lower than the corresponding value on the data sheets in Refs. (10) and (12), then the value in Refs. (10) and (12) was used. In general, the values presented in the TI appendix tables are the same as or higher than the values presented in Refs. (10) and (12) for the reason discussed by Con Edison in their response to Question VI.2 in Ref. (10). Thus, the substituted higher values from Refs. (10) and (12) can still be low, because they were selected by TI to include only data that represented known flow volumes and associated impingement collections.

Roseton

Number collected: May 1974 - June 1976: copied directly from Table 10.2-13 of Ref. (2).

Danskammer

Number collected: May 1974 - June 1976: calculated from the monthly average collection rates in Ref. (10) and monthly values of actual total plant intake flow in millions of gallons for the particular month obtained from data sheets in Ref. (9).

Albany

No bay anchovy are reported to be impinged at Albany (Refs. 3 and 4).

Table A-1. "DIVISION" criteria specified by Texas Instruments as the cut-off length between young-of-the-year and yearling striped bass<sup>a</sup>

DATE <sup>b</sup>	DIVISION <sup>c</sup> (mm)	YEAR CLASSES <sup>d</sup>	DATE <sup>b</sup>	DIVISION <sup>c</sup> (mm)	YEAR CLASSES <sup>d</sup>	
750101	140	1973-1974 ↓	760105	155	1974-1975 ↓	
750101	140		760119	155		
750116	140		760202	155		
750116	140		760216	155		
750201	140		760301	155		
750201	140		760315	155		
750215	140		760405	155		
750215	140		760419	155		
750301	140		760419	155		
750301	140		760503	155		
750315	140		760517	155		
750315	140		760607	50		1975-1976 ↓
750401	140		760607	50		
750401	140		760621	50		
750415	140		760705	50		
750415	140		760719	80		
750501	140		760802	80		
750501	140		760816	100		
750515	140		760816	100		
750515	140		760830	125		
750601	29	1974-1975 ↓	760830	125		
750601	29		760913	125		
750615	50		760913	125		
750615	50		760927	125		
750701	50		760927	125		
750701	50		761011	125		
750715	80		761011	125		
750715	80		761025	125		
750805	100		761025	125		
750805	100		761108	125		
750818	110		761108	125		
750901	110		761122	125		
750915	130		761206	125		
751006	150		761206	125		
751020	150		761220	125		
751103	150		761220	125		
751117	150					
751201	150					
751215	155					

<sup>a</sup>Obtained from computer data tapes entitled Texas Instruments 1975 Impingement Data (Record Type E) and Texas Instruments 1976 Impingement Data (Record Type E).

<sup>b</sup>The format for DATE is year-month-day.

<sup>c</sup>The seasonally-varying, total body length which is used to discriminate between young-of-the-year and yearling striped bass.

<sup>d</sup>The two year classes separated by DIVISION.

## REFERENCES FOR APPENDIX A

1. Orange and Rockland. 1977. Bowline Point Generating Station. Near-field Effects of Once-through Cooling System Operation on Hudson River Biota. Exhibit UT-7.
2. Central Hudson. 1977. Roseton Generating Station. Near-field Effects of Once-through Cooling System Operation on Hudson River Biota. Exhibit UT-6.
3. Lawler, Matusky & Skelly Engineers (LMS). Albany Steam Electric Generating Station Impingement Survey (April 1974 - March 1975). LMS Project No. 191-027. Prepared for Niagara Mohawk Power Corporation, June 1975.
4. Lawler, Matusky & Skelly Engineers (LMS). Albany Steam Electric Generating Station, 316(a) Demonstration Submission, NPDES Permit NY 0005959. Prepared for Niagara Mohawk Power Corporation, 1976.
5. Texas Instruments, Inc. (TI). Indian Point Impingement Study Report for the Period 15 June 1972 through 31 December 1973. Prepared for Consolidated Edison Company of New York, Inc., December 1974. (Tables A-1.5 through A-1.8).
6. Texas Instruments, Inc. (TI). Indian Point Impingement Study Report for the Period 1 January 1974 through 31 December 1974. Prepared for Consolidated Edison Company of New York, Inc., November 1975. (Tables B-2 through B-4).
7. Texas Instruments, Inc. (TI). Indian Point Impingement Study Report for the Period 1 January 1975 through 31 December 1975. Prepared for Consolidated Edison Company of New York, Inc., November 1976. (Tables A-4 and A-5).
8. Texas Instruments, Inc. (TI). Hudson River Ecological Study in the Area of Indian Point. 1976 Annual Report. Prepared for Consolidated Edison Company of New York, Inc., December 1977 (Tables A-2 and A-3).
9. Letter dated October 31, 1977, from Kenneth L. Marcellus of Consolidated Edison Company of New York, Inc. to Henry Gluckstern of the U. S. Environmental Protection Agency, including in Attachment 2 a response to Question 7 (9/27/77) of Attachment C which accompanied the October 12, 1977 EPA "Motion to Specify Area of Requestors' Testimony to Be Crossed-Examined During Initial Phase of Hearing."

10. Letter dated March 3, 1978, from William J. Cahill, Jr. of Consolidated Edison Company of New York, Inc., (Con Ed) to Robert P. Geckler of the U. S. Nuclear Regulatory Commission (USNRC), including a response to Questions VI.3 (Indian Point), IX.1 (Roseton and Danskammer), and X.1 (Bowline and Lovett), which are the identification numbers for questions in Enclosure 2 of a letter dated July 26, 1977, from Mr. George W. Knighton (USNRC) to Mr. William Cahill, Jr. (Con Ed).
11. Letter dated April 14, 1978, from Kenneth L. Marcellus of Consolidated Edison Company of New York, Inc. (Con Ed) to Henry Gluckstern of the U.S. Environmental Protection Agency (USEPA) including a response to Question A-5, which is the identification number for a question in the enclosure of a letter dated March 23, 1978, from Henry Gluckstern (USEPA) to Kenneth L. Marcellus (Con Ed).
12. Letter dated May 3, 1978, from Kenneth L. Marcellus of Consolidated Edison Company of New York, Inc. (Con Ed) to Henry Gluckstern of the U.S. Environmental Protection Agency (USEPA), including a response to Question A-3, which is the identification number for a question in the enclosure of a letter dated March 23, 1978, from Henry Gluckstern (USEPA) to Kenneth L. Marcellus (Con Ed).
13. Letter dated May 5, 1978, from Edward G. Kelleher of Consolidated Edison Company of New York, Inc. (Con Ed) to Henry Gluckstern of the U.S. Environmental Protection Agency (USEPA), including a response to Question A-4, which is the identification number for a question in the enclosure of a letter dated March 23, 1978, from Henry Gluckstern (USEPA) to Kenneth L. Marcellus (Con Ed).
14. Letters from Eugene R. McGrath of Consolidated Edison Company of New York, Inc. to Peter A. A. Berle of the New York State Department of Environmental Conservation, which are sent on a monthly basis as specified in the Section 401 Certification and which include data sheets giving daily fish counts by species for each unit at Indian Point.
15. Letters from William J. Cahill, Jr. of Consolidated Edison Company of New York, Inc. to James P. O'Reilly of the U.S. Nuclear Regulatory Commission, which are sent on a monthly basis as specified in Appendix B of Unit Nos. 1, 2, and 3 Technical Specifications and which include data sheets giving daily fish counts by species for each unit at Indian Point.
16. Letter dated March 21, 1979, from Kenneth L. Marcellus of Consolidated Edison Company of New York, Inc. (Con Ed) to Henry Gluckstern of the U.S. Environmental Protection Agency (USEPA), including a response to a question in the enclosure of a letter dated March 12, 1979, from Henry Gluckstern (USEPA) to Kenneth L. Marcellus (Con Ed).

## APPENDIX B

## ABUNDANCE AND MORTALITY ESTIMATES

Our estimates of white perch abundance and mortality are developed in a separate piece of testimony: "Evaluation of impingement losses of white perch at the Indian Point Nuclear Station and other Hudson River power plants" (Exhibit EPA-206). In this appendix we develop similar estimates for striped bass, blueback herring, alewife, American shad, and Atlantic tomcod. The bay anchovy is treated differently: instead of estimating the initial number of impingeable juveniles and the rate of mortality of these juveniles, the total number of juveniles and adults residing above RM 12 is estimated. The reason for this difference in treatment is discussed in Section I of the main body of testimony.

All of these estimates are based on data from TI's Long River Survey and Riverwide Beach Seine Survey for the years 1974 and 1975. Although the data bases used vary from species to species, the population sizes and mortality rates for all species except striped bass and bay anchovy were computed using a common method. This method is described in Section B1 of this appendix. Sections B2-B5 describe the data bases and computations used to derive abundance and mortality estimates for each individual species.

B1. Methodology for Estimating Abundance and Mortality of  
Blueback Herring, Alewife, American Shad, and Atlantic Tomcod

The data used to compute estimates of initial abundance and mortality for blueback herring, alewife, American shad, and Atlantic tomcod are weekly (Long River Survey) or biweekly (Beach Seine Survey) estimates of the number of juveniles present between River Miles 12 and 156. The methods used to derive these estimates are described in Section B3 and B4. The purpose of this section is to describe the way in which estimates of initial abundance and mortality were generated from each time series of population sizes.

In general, it was not possible to identify a single weekly or biweekly population estimate as being the "best" estimate of the initial number of impingeable juveniles. For some species in some years, significant impingement began before juveniles were fully recruited into the size range catchable by the sampling gear. In other cases the variability among successive estimates was so high that it was impossible to determine during which sampling period recruitment to the beach seine was completed. Therefore, we used linear regression to calculate both the initial numbers of impingeable juveniles and the mortality rates. Our regression procedure was the same as that used by TI to estimate the daily total mortality rate of juvenile striped bass (Exhibit UT-4, p. 7.137). The procedure involves regressing the logarithms of the successive population estimates against the time elapsed, in days, since some conveniently chosen starting date (we chose as the starting date for each year class the first day of its period of vulnerability to impingement). The y-axis intercept of the fitted

regression line is an estimate of the natural logarithm of population size on day 0 and the slope is an estimate of the daily total mortality rate:

$$\log P(t) = \log P_0 - Dt \quad , \quad (B1)$$

where  $P(t)$  = population size at time  $t$ ,  $P_0$  = initial population size, and  $D$  = daily total mortality rate. This equation is equivalent to the equation that describes the exponential decline of abundance when the mortality rate is constant:

$$P(t) = P_0 e^{-Dt} \quad . \quad (B2)$$

A problem encountered in the application of this method is that of deciding which population estimates should be included in the regression. Early summer values derived from beach seine data are likely to be erroneously low because not all of the juveniles have grown large enough to be caught by this gear. Late fall population estimates for blueback herring, alewife and American shad are likely to be erroneously low because of emigration of juveniles from the estuary. Because of the relatively high variability in the data, it is impossible to unambiguously identify cutoff points for the analysis. Therefore, we performed a series of regressions for each species, using different combinations of weekly or biweekly population estimates. Rather than singling out one regression as providing the "best" estimates of  $\log P_0$  and  $D$ , we computed weighted means of the individual estimates. The weighting factor used was the inverse of the mean squared error associated with each regression. This procedure gives the greatest weight to those values of  $\log P_0$  and  $D$  associated with the regressions having the best fit to the data. The total mortality rate for month  $i$  ( $A_i$ ) was calculated from the weighted mean value of  $D$  by means of the following equation:

$$A_i = 1 - e^{-d_i D} \quad , \quad (B3)$$

where  $d_i$  = number of days in month  $i$ .

## B2. Striped Bass

Estimates of striped bass abundance and mortality are taken directly from TI's combined shoal, channel, bottom, and shorezone population estimates for 1974 and 1975 (described in Exhibit UT-4, Section 7.9.1.4). All weekly standing crop values for the period July-December for both years were provided to EPA on February 27, 1978 (Tables D.3-1 and D.3-2) in response to an information request dated December 27, 1977. The same response contains a description of the method used to derive these values.

The utilities used the combined gear population estimate for the period 7/27 - 8/2, 1975 (5.3 million) as their estimate of the initial number of impingeable juvenile striped bass during that year. We have taken the same value as our estimate of the minimum number of impingeable juveniles alive on August 1, 1975. A similar estimate of the minimum abundance of striped bass juveniles on August 1, 1974 was obtained from TI's combined gear estimate for the period 7/29-8/2, 1974 (3.8 million). These estimates are minimum estimates because they were calculated with no adjustments for gear efficiency.

TI's combined gear population estimates are derived by assuming that each of the three gears employed (epibenthic sled, Tucker trawl, and 100-foot beach seine) is 100% efficient at catching the fish in its path. It is undoubtedly true, however, that the efficiencies of all of these gears are far less than 100%, and most likely less than 50%. Recent tests conducted by Texas Instruments (1978) have indicated that the efficiency of the 100-foot beach seine at catching juvenile striped bass is about 40%. No attempts have been made to calculate the absolute efficiency (as opposed to relative efficiency in comparison to other gears) of the epibenthic sled or Tucker trawl. However, these are basically ichthyoplankton gears, designed to capture eggs and larvae. Their efficiencies at catching the more mobile juveniles should be lower than that of the beach seine, which is designed to capture juvenile fish. Therefore, we have generated maximum striped bass juvenile abundance estimates for 1974 and 1975 by assuming that the average efficiency of the three gears combined is 20%.

In Section 7.7.4 of Exhibit UT-4, TI computed an estimate of D for juvenile striped bass (0.0048) based on the combined gear population estimates for the period 7/26-12/31, 1975. The method used by TI to obtain this estimate is discussed in section B1 of this Exhibit. The value of A (0.8) used in the utilities' impingement impact assessment (Exhibit UT-3, Section 2-VI) was derived by extrapolating TI's result to 365 days,

$$A = 1 - e^{-365 \times 0.0048} = 0.8266 \quad , \quad (B4)$$

and then rounding off. We believe that the utilities' estimate of A is probably an overestimate of the annual total mortality of juvenile striped bass. The data used in TI's regression was collected during the late summer and early fall (Exhibit UT-4, Fig. 7.7-7), a time of high predator activity and, consequently, high mortality. Mortality during the remainder of the period of vulnerability to impingement is likely to be lower. Both the food requirements of the predators (primarily piscivorous fish) and the rates at which they can capture and digest prey are undoubtedly influenced by water temperature. During the winter months mortality due to predation is likely to be reduced because of lower predator activity. As the juvenile striped bass grow they become less vulnerable to predators. By late spring the surviving fish are on the average more than 100 mm long, nearly twice as long as they were the previous July (50 to 60 mm). For a similar reason

TI's mortality estimate is likely to be high, even for the period during which the abundance data were collected. As the juveniles grow, their ability to evade capture by the gear increases. Gradual reductions in gear efficiency will cause the population estimates to decline more rapidly than does the actual size of the population.

Based on the above reasoning we have used 0.8 as an upper bound on the annual total mortality rate of juvenile striped bass. The corresponding daily mortality rate is 0.0044. The estimated total annual mortality rate of yearling and older white perch provides a reasonable lower bound on juvenile striped bass mortality. Data collected by LMS (Dew 1978), as analysed by Van Winkle and Barnthouse (Exhibit EPA-206), indicate that  $A$  is about 0.5 for yearling and older white perch. Mortality should be at least as high as this among the smaller juvenile striped bass. This value corresponds to a daily mortality rate of 0.0019. Our estimates of the minimum and maximum abundance of juvenile striped bass in 1974 and 1975, and our estimates of minimum and maximum juvenile mortality during both years, are presented in Table B1. We have chosen July 16, rather than August 1, as the beginning of the period of vulnerability of striped bass juveniles to power plant impingement. Estimates of July 16 abundance were obtained by extrapolating the August 1 abundance estimates backward in time, using the maximum and minimum mortality rates. The resulting estimates of initial population size are presented in Table B1.

TI conducts a mark/recapture program for juvenile striped bass that is identical to the white perch mark/recapture program that provided the data used to compute estimates of white perch juvenile abundance. Although in our opinion population estimates based on marking experiments are generally superior to estimates obtained from fish survey data, the striped bass mark/recapture estimates do not appear to be useable for impact assessment. According to the results of the striped bass marking studies (Exhibit UT-4, Table 7.9-1), only about 1 million juveniles were present in the Hudson in October of 1974 and 1975. This value seems suspiciously low. We have used the maximum striped bass mortality rate and the minimum August 1 striped bass population sizes (Table B1) to compute minimum population sizes at the end of October. The results indicate that at least 2.5 million juveniles were alive on October 31, 1974 and that at least 3.5 million were alive on October 31, 1975. A fraction of striped bass juveniles emigrate from the Hudson during the fall (Exhibit UT-4, Section 7.5.4.4). TI has captured some of these fish (as yearlings) from bays around the southwest end of Long Island and from the Hackensack River (Exhibit UT-4, Table 7.6-1). The mark/recapture estimates are obtained by releasing marked fish in the fall and recapturing them the following spring. It seems likely that the mark/recapture estimates for juvenile striped bass are estimates not of the entire year class but of that fraction that remains in the Hudson.

Table B1. Juvenile striped bass abundance and mortality estimates

Year	August 1 abundance <sup>a</sup>		Daily mortality rate (D)		Minimum initial population (P <sub>0</sub> ) <sup>b</sup>		Maximum initial population (P <sub>0</sub> ) <sup>c</sup>	
	Minimum	Maximum	Minimum	Maximum	Minimum mortality	Maximum mortality	Minimum mortality	Maximum mortality
1974	3.8x10 <sup>6d</sup>	19.0x10 <sup>6</sup>	0.0019	0.0044	3.92x10 <sup>6</sup>	4.08x10 <sup>6</sup>	19.59x10 <sup>6</sup>	20.39x10 <sup>6</sup>
1975	5.3x10 <sup>6e</sup>	26.5x10 <sup>6</sup>	0.0019	0.0044	5.46x10 <sup>6</sup>	5.69x10 <sup>6</sup>	27.3x10 <sup>6</sup>	28.43x10 <sup>6</sup>

<sup>a</sup>Minimum abundance estimate divided by gear efficiency adjustment factor (0.2).

<sup>b</sup>August 1 abundance extrapolated backward to July 16 using minimum estimate of D.

<sup>c</sup>August 1 abundance extrapolated backward to July 16 using maximum estimate of D.

<sup>d</sup>Texas Instruments striped bass juvenile population estimate for 7/29-8/2, 1974.

<sup>e</sup>Texas Instruments striped bass juvenile population estimate for 7/27-8/2, 1975.

### B3. Blueback Herring, Alewife, and American Shad

Estimates of blueback herring, alewife, and American shad abundance and mortality were derived from TI's daytime riverwide beach seine data. This data base was used for two reasons. First, after August 15 the only gears used by TI are the beach seine, epibenthic sled, and bottom trawl. Of these, only the beach seine is deployed in strata in which these species are abundant. All three species are surface-oriented and are rarely caught in the epibenthic sled and bottom trawl. Second, although TI conducted both a daytime and a nighttime beach seine survey in 1974, only the daytime survey was conducted in 1975. Moreover, the upper estuary (above the Cornwall region) was sampled only during the day in 1974.

Biweekly beach seine density estimates, broken down by region, for young-of-the-year blueback herring (1974), alewife (1974), and American shad (1975) were provided to EPA on November 30, 1977 in response to an information request made on September 27, 1977. Similar beach seine densities for American shad (1974) are contained in Table A-58 of TI's 1974 Year Class Report (Texas Instruments 1977). We scaled up the biweekly density indices to absolute population estimates using the method employed by LMS in Section 3-VII of Exhibit UT-3. LMS assumed that the densities of striped bass juveniles in the beach seine samples, measured as fish per unit bottom area, are characteristic of the entire area of the river. As applied to alewife, blueback herring, and American shad, the assumption is that the catch per unit area computed from the beach seine data is characteristic of the entire surface area of the river. The equation used in LMS' computations and the total bottom area of each of TI's 12 river regions were provided to EPA on November 30, 1977 in response to an information request made on October 12, 1977. We have used the same equation and areas in our own computations. For the reader's convenience we have reproduced these areas in Table B2. Using the bottom area of each region as an estimate of the surface area will yield slightly inflated estimates of abundance (resulting in slightly lower estimates of impact), but the errors thus introduced are certainly small in comparison to sampling error.

The biweekly population estimates computed from the beach seine data are presented in Tables B3 (blueback herring, alewife, and American shad; 1974) and Table B4 (American shad; 1975). Day 0, the beginning of the period of vulnerability to impingement, was set at July 1 for alewife and blueback herring and June 16 for American shad. The values of  $t$ , i.e., the number of days since day 0, assigned to each biweekly estimate were computed from the mid-point of each period. The values are listed in Tables B3 and B4, along with the corresponding population sizes. Four sets of estimates were used to compute weighted mean values of  $\log P_0$  and  $D$  for blueback herring and alewife: 7/13-11/15, 7/27-11/1, 7/27-11/15, and 7/15-11/1. For the 1974 American shad year class the periods used were 6/29-11/15, 7/27-11/1, 7/27-11/15, and 7/13-11/1. For the 1975 American shad year class the periods used were 6/15-11/15, 7/27-11/15, 6/29-11/15, and 7/13-11/15. The intercepts, slopes, and mean squared errors derived from each of the regressions, as well as the weighted mean slopes and intercepts, are listed in Tables B5-B8.

Table B2. Method used to estimate regional abundances of juvenile blueback herring, alewife, American shad and bay anchovy

River region (river miles) <sup>a</sup>	Estimated total bottom area (m <sup>2</sup> )
YK (14-23)	2.0406x10 <sup>7</sup>
TZ (24-33)	5.0034x10 <sup>7</sup>
CH (34-38)	3.0609x10 <sup>7</sup>
IP (39-46)	1.8836x10 <sup>7</sup>
WP (47-55)	9.2220x10 <sup>6</sup>
CW (56-61)	1.7855x10 <sup>6</sup>
PK (62-76)	2.4134x10 <sup>7</sup>
HP (77-85)	1.0988x10 <sup>7</sup>
KG (86-93)	1.5893x10 <sup>7</sup>
SG (94-106)	2.4526x10 <sup>7</sup>
CS (107-124)	2.8541x10 <sup>7</sup>
AL (125-154)	1.5697x10 <sup>7</sup>

Equation Used to Compute Absolute Abundance

$$N_r = \frac{CPUE_r \times (A_T)_r}{A_S}$$

$N_r$  = juvenile abundance in region r

$CPUE_r$  = mean biweekly catch per unit effort in region r

$A_S$  = estimated surface area swept by 100 foot beach seine as deployed by Texas Instruments (= 450 m<sup>2</sup>)

$(A_T)_r$  = estimated total bottom area of sampling region r

<sup>a</sup>Regions defined by Texas Instruments (Exhibit UT-4, Table 6.1-1).

Table B3. Unadjusted biweekly juvenile population estimates for the 1974 year classes of blueback herring, alewife and American shad

Period	Blueback herring	Alewife	t <sup>a</sup>	American shad	t <sup>b</sup>
6/29-7/12	--	--	-	5.98x10 <sup>6</sup>	19
7/13-7/26	15.5x10 <sup>6</sup>	2.31x10 <sup>6</sup>	18	7.05x10 <sup>6</sup>	33
7/27-8/9	35.1x10 <sup>6</sup>	6.76x10 <sup>6</sup>	32	10.9x10 <sup>6</sup>	47
8/10-8/23	19.1x10 <sup>6</sup>	0.928x10 <sup>6</sup>	46	8.01x10 <sup>6</sup>	61
8/24-9/6	11.9x10 <sup>6</sup>	2.11x10 <sup>6</sup>	60	9.29x10 <sup>6</sup>	75
9/7-9/20	11.9x10 <sup>6</sup>	1.06x10 <sup>6</sup>	74	7.35x10 <sup>6</sup>	89
9/21-10/4	6.91x10 <sup>6</sup>	0.948x10 <sup>6</sup>	88	6.02x10 <sup>6</sup>	103
10/5-10/18	29.9x10 <sup>6</sup>	0.866x10 <sup>6</sup>	102	6.99x10 <sup>6</sup>	117
10/19-11/1	5.76x10 <sup>6</sup>	1.04x10 <sup>6</sup>	116	4.08x10 <sup>6</sup>	131
11/2-11/15	11.1x10 <sup>6</sup>	0.952x10 <sup>6</sup>	130	2.44x10 <sup>6</sup>	145

<sup>a</sup>Number of days elapsed since July 1, measured from midpoint of biweekly period.

<sup>b</sup>Number of days elapsed since June 16, measured from midpoint of biweekly period.

Table B4. Unadjusted biweekly juvenile population estimates for the 1975 year class of American shad

Period	American shad	t <sup>a</sup>
6/15-6/28	6.39x10 <sup>6</sup>	5
6/29-7/12	5.80x10 <sup>6</sup>	19
7/13-7/26	9.81x10 <sup>6</sup>	33
7/27-8/9	13.3x10 <sup>6</sup>	47
8/10-8/23	4.34x10 <sup>6</sup>	61
8/24-9/6	7.69x10 <sup>6</sup>	75
9/7-9/20	6.01x10 <sup>6</sup>	89
9/21-10/4	4.19x10 <sup>6</sup>	103
10/5-10/18	6.03x10 <sup>6</sup>	117
10/19-11/1	2.14x10 <sup>6</sup>	131
11/2-11/15	1.75x10 <sup>6</sup>	145

<sup>a</sup>Number of days elapsed since June 16, measured from midpoint of biweekly period.

Table B5. Computation of initial abundance and mortality of impingable blueback herring, 1974

Inclusive dates <sup>a</sup>	Intercept (logP <sub>0</sub> )	Slope (-D)	Mean squared error
7/13-11/15	17.0120	-0.007624	0.3196
7/27-11/1	17.4214	-0.012931	0.3878
7/27-11/15	17.2492	-0.010061	0.3457
7/13-11/1	17.0902	-0.009168	0.3620

Weighted Mean Intercept = 17.1843<sup>b</sup>

P<sub>0</sub> = 29.0x10<sup>6</sup>

Weighted Mean Slope = -0.0098<sup>b</sup>

D = 0.0098 (1/days)

<sup>a</sup>First day of first biweekly period used in regression through last day of last biweekly period.

<sup>b</sup>Weighting factor for slope and intercept derived from each regression = (1/mean squared error).

Table B6. Computation of initial abundance and mortality of impingable alewife, 1974

Inclusive dates <sup>a</sup>	Intercept ( $\log P_0$ )	Slope (-D)	Mean squared error
7/13-11/15	15.0687	-0.012023	0.2940
7/27-11/1	15.4074	-0.017719	0.3657
7/27-11/15	15.2173	-0.013550	0.3323
7/13-11/1	15.1698	-0.014018	0.3248

Weighted Mean Intercept = 15.2065<sup>b</sup>

$P_0 = 4.0 \times 10^6$

Weighted Mean Slope = -0.0140<sup>b</sup>

D = 0.0140 (1/days)

<sup>a</sup>First day of first biweekly period used in regression through last day of last biweekly period.

<sup>b</sup>Weighting factor for slope and intercept derived from each regression = (1/mean squared error).

Table B7. Computation of initial abundance and mortality of juvenile American shad, 1974

Inclusive dates <sup>a</sup>	Intercept ( $\log P_0$ )	Slope (-D)	Mean squared error
6/29-11/15	16.2026	-0.006584	0.1185
7/27-11/1	16.6221	-0.009322	0.0254
7/27-11/15	16.8735	-0.012673	0.0520
7/13-11/1	16.2874	-0.006072	0.0502

Weighted Mean Intercept = 16.5602<sup>b</sup>

$P_0 = 15.6 \times 10^6$

Weighted Mean Slope = -0.0091<sup>b</sup>

D = 0.0091 (1/days)

<sup>a</sup>First day of first biweekly period used in regression through last day of last biweekly period.

<sup>b</sup>Weighting factor for slope and intercept derived from each regression = (1/mean squared error).

Table B8. Computation of initial abundance and mortality of juvenile American shad, 1975

Inclusive dates <sup>a</sup>	Intercept (logP <sub>0</sub> )	Slope (-D)	Mean squared error
6/15-11/15	16.1597	-0.009031	0.2030
7/27-11/15	16.9069	-0.016006	0.1587
6/29-11/15	16.3776	-0.011147	0.1921
7/13-11/15	16.7572	-0.014673	0.1430

Weighted Mean Intercept = 16.5875<sup>b</sup>

P<sub>0</sub> = 16.0x10<sup>6</sup>

Weighted Mean Slope = -0.0131<sup>b</sup>

D = 0.0131 (1/days)

<sup>a</sup>First day of first biweekly period used in regression through last day of last biweekly period.

<sup>b</sup>Weighting factor for slope and intercept derived from each regression = (1/mean squared error).

The initial population sizes ( $P_0$ ) computed from the regressions are probably underestimates of the actual numbers of juvenile blueback herring, alewife, and American shad, since they assume that the beach seine is 100% efficient at catching the fish in its path. They could be overestimates of abundance only if the density of these fish, measured as number per unit surface area, is much higher in the shorezone than in deeper water. As a check on this possibility, we have compared our estimate of American shad abundance on July 1, 1974 to similar estimates calculated by TI from the Long River Survey data. TI's estimates, contained in Tables A-57 of the 1974 Year Class Report (Texas Instruments 1977), are derived from data collected in strata inaccessible to the beach seine: the shoals, bottom, and channel. If these estimates were considerably lower than those derived from the beach seine data, this could be evidence that estimates based on extrapolation of beach seine data are erroneously high. In fact, the Long River Survey estimates are slightly higher than are our beach seine estimates. TI's estimate for the period July 8-11, 1974 is 17.7 million juveniles, compared to our July 1 estimate of 13.6 million. Moreover, TI did not sample the entire river that week. If the Saugerties, Catskill and Albany regions had been sampled, TI's estimates would probably have been increased by several million. Thus, comparison of our beach seine estimates to TI's estimates based on epibenthic sled and Tucker trawl data indicates that juvenile American shad are not anomalously abundant in the shorezone. Similar findings are discussed by Boreman (Exhibit EPA-198). Since similar comparisons are not possible for alewife and blueback herring, we assume that this conclusion holds for all three of these closely related species.

Because no corrections have been made for gear efficiency, the unadjusted estimates of  $P_0$  obtained from the regressions are lower bounds on the initial numbers of impingeable blueback herring, alewife, and American shad. TI has not estimated the efficiency of the 100-foot beach seine at catching these species. Kjelson (1977) found the efficiency of the 350 meter (1148 ft) haul seine to be 41% for pelagic fish such as these clupeids. A 21-meter (69 ft) haul seine was found by Kjelson to be 56% efficient at catching the rough silversides, a pelagic species. Thus, haul seines both larger and smaller than the 100-foot seine used by TI have been found to be greater than 40% efficient at catching pelagic fish. It is, of course, possible that because of differences in bottom morphometry or deployment technique TI's beach seine hauls are less efficient than those of Kjelson. It is also possible that the blueback herring, alewife, and American shad are less abundant in the shorezone than in deeper water. Therefore, although a value for gear efficiency as high as 40% might have been justifiable, we chose a lower value in an effort to ensure that our maximum population sizes are higher than the actual abundances of juvenile blueback herring, alewife, and American shad. We have computed maximum population sizes for these species by assuming that the 100-foot beach seine, as deployed by TI, is only 20% efficient at estimating the true number of fish per unit surface area within each river region. The minimum and maximum estimates of the initial numbers of impingeable juveniles for each species and year are tabulated in Table B9.

Table B9. Juvenile blueback herring, alewife and American shad abundance and mortality estimates

Species	Initial population ( $P_0$ )		Daily mortality rate (D, 1/days)	
	Minimum <sup>a</sup>	Maximum <sup>b</sup>	Jul.1-Oct.31 <sup>a</sup>	Oct.1-June 30 <sup>c</sup>
Blueback herring (1974)	29.0x10 <sup>6</sup>	145.0x10 <sup>6</sup>	0.0098	0.0044
Alewife (1974)	4.0x10 <sup>6</sup>	20.0x10 <sup>6</sup>	0.0140	0.0044
American shad (1974)	15.6x10 <sup>6</sup>	78.0x10 <sup>6</sup>	0.0091	0.0044
American shad (1975)	16.0x10 <sup>6</sup>	80.0x10 <sup>6</sup>	0.0131	0.0044

<sup>a</sup>Derived from regressions summarized in Tables B5-B8.

<sup>b</sup>Minimum abundance estimate divided by gear efficiency adjustment factor (0.2).

<sup>c</sup>Assumed equal to maximum estimate of D for juvenile striped bass.

The daily mortality rate estimates (D) derived for all three species are far higher than that derived by TI for striped bass (Section B2). If extrapolated for 365 days, they lead to estimates of total annual mortality that seem unrealistically high for fish that are large enough to be impinged: 96 to 99%. However, it is more realistic to extrapolate the daily mortality rates for only 120 days, roughly from early July to early November, the approximate period during which these fish are resident in the estuary. Extrapolation for 120 days leads to estimates of mortality that are much more reasonable, although still relatively high: 66 to 80%. Since predators are attracted to the productive nursery areas of the lower estuary, it seems likely that the mortality of juvenile blueback herring, alewife, and American shad is reduced after they emigrate to the ocean. A few of these fish remain in the estuary instead of emigrating, and some of these are impinged the following spring. In order to estimate the impact of impinging these fish, we have assumed that they are subject to the same rate of total mortality as that which was computed from TI's estimate of A for juvenile striped bass ( $D = 0.0044$ ). A few two-year old alewife and blueback herring belonging to the 1974 year classes of these species were impinged during the spring of 1976, and a fairly large number (10,000 of each species) were impinged, presumably as returning spawners, in 1977. In order to estimate the total impact of impingement on these year classes over a three-year period of vulnerability, we assumed that the daily rate of mortality of yearling and older alewife and blueback herring is the same as that of yearling and older white perch ( $D = 0.0019$ ). These particular values were chosen primarily for convenience, in the absence of data relating to the mortality rates of these three species after emigration from the estuary. Since the assumed rates are empirical estimates of mortality rates in other fish species, they are biologically reasonable, but we have no way of knowing how close they are to the actual mortality rates of blueback herring, alewife, and American shad.

As a check on the reliability of results obtained from the application of the Empirical Impingement Model to alewife (Section 3.3), we computed estimates of alewife spawning stock size in 1974 and 1975. These estimates were compared to estimates of three-year-old abundance obtained from the model. Data from TI's 1974 and 1975 Riverwide Beach Seine Survey (extracted from TI's 1974 and 1975 fisheries data tapes, provided to EPA on October 31, 1977) were used to derive these spawning stock estimates. The method used was identical to that used to estimate juvenile abundance from the beach seine data, except that:

- (1) Estimates of mean CPUE were calculated on a monthly rather than a biweekly basis. Since we wanted estimates of the mean riverwide abundance of adult alewives during May, we computed the mean CPUE, by region, for all sampling dates between May 1 and May 31.
- (2) The regional CPUE values were scaled up using shorezone areas rather than total river surface areas, since alewives spawn in shallow water. The shorezone areas were obtained from Table A-2 of TI's 1974 Year Class Report (Texas Instruments 1977).

The spawning stock estimates so obtained are presented in Table 14 (Section 3). Since these estimates include only fish present in the shorezone, and since they are not corrected for gear efficiency, they represent minimum estimates of spawner abundance.

#### B4. Atlantic Tomcod

TI's Long River Survey data were used to compute estimates of Atlantic tomcod abundance and mortality. Since this species is most abundant near the bottom in deep water (Exhibit UT-4, Section 6.3.3), the beach seine data are likely to greatly underestimate its abundance. The habitats preferred by the Atlantic tomcod are, however, sampled with the epibenthic sled as part of the Long River Survey. Weekly standing crop estimates for the period April 29-August 15, 1974, were provided to EPA on October 31, 1977 in response to an information request dated October 12, 1977. Similar estimates for the 1975 Atlantic tomcod year class are tabulated in Table B-22 of TI's 1975 Year Class Report (Texas Instruments 1978).

The method used to compute estimates of  $\log P_0$  and  $D$  for Atlantic tomcod was identical to that used for blueback herring, alewife, and American shad. Our method is also similar to that used by the utilities in Section 2-VII of Exhibit UT-3, with one exception: in addition to the Long River Survey abundance estimates, the utilities included estimates of January egg abundance and December spawner abundance in their regression. According to the response of October 31, 1977 (Exhibit 4, question 2, Attachment D), these estimates were derived from mark/recapture data and fecundity. Since the biases associated with mark/recapture data are likely to be quite different from those associated with the Long River Survey data, we do not believe the two types of data should be used in the same regression.

Since few juvenile Atlantic tomcod are impinged before mid-May, we have taken day 0 to be May 15 for this species. Only two sets of population estimates were used in the regression analysis for each year class: 4/29-8/15 and 5/15-8/15 for 1974; 5/13-8/15 and 5/19-8/15 for 1975. The weekly population estimates for both years and their associated values of  $t$  (the number of days since day 0) are listed in Table B10. The intercepts, slopes, and mean squared errors derived from each individual regression and the weighted mean slopes and intercepts are listed in Table B11.

Like the abundance estimates for blueback herring, alewife, American shad, and striped bass, those derived for Atlantic tomcod assume 100% collection efficiency and thus are undoubtedly underestimates of the actual abundance of this species. As no estimates of the collection efficiencies of the epibenthic sled and Tucker trawl are available, we have simply assumed that these gears are no less efficient than the 100-foot beach seine. Accordingly, we have computed maximum abundances for both year classes by assuming that the epibenthic sled and Tucker trawl are 20% efficient at

Table B10. Unadjusted weekly estimates of Atlantic tomcod juvenile abundance

1974			1975		
Period	Population size	t	Period	Population size	t
4/29-5/04	1214.6x10 <sup>6</sup>	-14	5/12-5/14	120.5x10 <sup>6</sup>	-2
5/06-5/11	145.5x10 <sup>6</sup>	-7	5/19-5/23	180.9x10 <sup>6</sup>	6
5/13-5/18	131.8x10 <sup>6</sup>	0	5/26-5/29	35.0x10 <sup>6</sup>	12
5/23-5/29	162.5x10 <sup>6</sup>	11	6/02-6/06	40.9x10 <sup>6</sup>	20
5/30-6/05	110.0x10 <sup>6</sup>	18	6/09-6/14	77.8x10 <sup>6</sup>	27
6/12-6/17	207.1x10 <sup>6</sup>	30	6/16-6/19	15.8x10 <sup>6</sup>	33
6/17-6/23	77.9x10 <sup>6</sup>	36	6/23-6/26	17.4x10 <sup>6</sup>	40
6/24-6/27	166.0x10 <sup>6</sup>	41	6/30-7/04	44.3x10 <sup>6</sup>	48
7/01-7/05	103.0x10 <sup>6</sup>	49	7/07-7/10	28.1x10 <sup>6</sup>	54
7/08-7/11	92.1x10 <sup>6</sup>	55	7/14-7/17	26.2x10 <sup>6</sup>	61
7/15-7/18	106.0x10 <sup>6</sup>	62	7/21-7/24	16.4x10 <sup>6</sup>	68
7/22-7/26	74.2x10 <sup>6</sup>	70	7/28-7/31	8.6x10 <sup>6</sup>	75
7/29-8/02	31.8x10 <sup>6</sup>	77	8/11-8/14	14.3x10 <sup>6</sup>	89
8/05-8/09	52.5x10 <sup>6</sup>	84			
8/12-8/15	53.2x10 <sup>6</sup>	91			

<sup>a</sup>Provided to EPA in a response dated October 31, 1977 (Exhibit UT-4, Question 2, Attach. D).

<sup>b</sup>From Table B-22 of 1975 Year Class Report (Texas Instruments 1978).

<sup>c</sup>Calculated from TI Long River Survey data.

<sup>d</sup>Number of days elapsed since May 15, measured from midpoint of sample period.

Table B11. Computation of initial abundance and mortality of impingeable Atlantic tomcod, 1974 and 1975

Inclusive dates <sup>a</sup>	Intercept ( $\log P_0$ )	Slope ( $-D$ 1/days)	Mean squared error
<u>1974</u>			
4/29-8/15	19.3126	-0.018869	0.2996
5/13-8/15	19.0271	-0.014031	0.1281
Weighted Mean Intercept = 19.1126 <sup>b</sup>			
$P_0 = 199.8 \times 10^6$			
Weighted Mean Slope = -0.0155 <sup>b</sup>			
$D = 0.0155$			
<u>1975</u>			
5/12-8/14	18.3190	-0.025067	0.3212
5/19-8/14	18.2332	-0.023481	0.3455
Weighted Mean Intercept = 18.2777 <sup>b</sup>			
$P_0 = 86.7 \times 10^6$			
Weighted Mean Slope = -0.0244 <sup>b</sup>			
$D = 0.0244$			

<sup>a</sup>First day of first biweekly period used in regression through last day of last biweekly period.

<sup>b</sup>Weighting factor for slope and intercept derived from each regression =  $(1/\text{mean squared error})$ .

catching juvenile Atlantic tomcod. The daily mortality rates and maximum and minimum estimates of the abundance of each year class are tabulated in Table B12.

#### B5. Bay Anchovy

Although derived from TI's beach seine data, our estimates of the abundance of impingeable bay anchovy were not computed in the same way as were the abundance estimates for blueback herring, alewife, and American shad. As was noted in Section 1, we have not attempted to compute conditional impingement mortality rates for this species, and therefore, estimates of the initial number of impingeable juveniles are not required. Instead of using regression analysis to estimate an initial population size, we have simply calculated an average population size (juveniles + adults) for each month from May through October. Beach seine density indices for the years 1974 and 1975, computed on a biweekly basis, were provided to EPA on June 23, 1978 in response to an information request made on September 27, 1977. Densities for young-of-the-year and for yearling and older bay anchovy were tabulated separately. We computed biweekly standing crops for each age group using the method described in Section B1 of this appendix, and then we summed the age groups to obtain an estimate of the total population for each biweekly period. Estimates of the average population size for each month were calculated as weighted means of the biweekly population estimates. The weighting factors are the number of days within each biweekly period that fall within a given month. For example, the June 29-July 12 abundance estimate is given a weighting factor of 2 in the computation of the average June population and a weighting factor of 12 in the computation of the average July population, since two days of that period fall in June and 12 fall in July.

The biweekly and monthly population estimates are tabulated in Table B13. As for all other abundance estimates derived from beach seine data, the unadjusted estimates in Table B13 are underestimates of the actual abundance of juvenile and adult bay anchovy. Therefore, as we did for all of the other species treated in this Appendix, we have computed maximum bay anchovy population sizes by assuming a minimum gear efficiency of 20%. However, in this case the maximum and minimum estimates refer only to the portion of the bay anchovy population residing above River Mile 12. Unlike the other species considered in this testimony, the bay anchovy is restricted primarily to the lower estuary, and an unknown fraction of the population resides below the region sampled by TI. This, of course, means that the exploitation rates presented in Section 3 apply only to that portion of the Hudson River bay anchovy population above RM 12.

Table B12. Juvenile Atlantic tomcod abundance and mortality estimates

Year	<u>Initial population (<math>P_0</math>)</u>		Daily mortality rate (D) units
	Minimum <sup>a</sup>	Maximum <sup>b</sup>	
1974	199.8x10 <sup>6</sup>	999.0x10 <sup>6</sup>	0.0155
1975	86.7x10 <sup>6</sup>	433.5x10 <sup>6</sup>	0.0244

<sup>a</sup>Derived from regressions summarized in Table B11.

<sup>b</sup>Minimum abundance estimate divided by gear efficiency adjustment factor (0.2).

Table B13. Biweekly and monthly estimates of the total abundance of impingeable bay anchovy (juveniles + adults), 1974 and 1975

1974 <sup>a</sup>			1975 <sup>a</sup>		
Period	Minimum abundance	Maximum abundance <sup>b</sup>	Period	Minimum abundance	Maximum abundance <sup>b</sup>
4/20-5/03	1.8x10 <sup>6</sup>	--	4/20-5/03	0.0	--
5/04-5/17	7.0x10 <sup>6</sup>	--	5/04-5/17	3.4x10 <sup>6</sup>	--
5/18-5/31	36.7x10 <sup>6</sup>	--	5/18-5/31	19.7x10 <sup>6</sup>	--
6/01-6/14	27.9x10 <sup>6</sup>	--	6/01-6/14	6.9x10 <sup>6</sup>	--
6/15-6/28	5.3x10 <sup>6</sup>	--	6/15-6/28	4.6x10 <sup>6</sup>	--
6/29-7/12	5.7x10 <sup>6</sup>	--	6/29-7/12	5.2x10 <sup>6</sup>	--
7/13-7/26	4.1x10 <sup>6</sup>	--	7/13-7/26	2.7x10 <sup>6</sup>	--
7/27-8/09	11.3x10 <sup>6</sup>	--	7/27-8/09	9.0x10 <sup>6</sup>	--
8/10-8/23	17.9x10 <sup>6</sup>	--	8/10-8/23	20.6x10 <sup>6</sup>	--
8/24-9/06	46.2x10 <sup>6</sup>	--	8/24-9/06	8.3x10 <sup>6</sup>	--
9/07-9/20	10.9x10 <sup>6</sup>	--	9/07-9/20	29.0x10 <sup>6</sup>	--
9/21-10/04	8.3x10 <sup>6</sup>	--	9/21-10/04	25.3x10 <sup>6</sup>	--
10/04-10/18	13.7x10 <sup>6</sup>	--	10/04-10/18	4.8x10 <sup>6</sup>	--
10/19-11/01	0.7x10 <sup>6</sup>	--	10/19-11/01	1.7x10 <sup>6</sup>	--
May <sup>c</sup>	19.9x10 <sup>6</sup>	99.5x10 <sup>6</sup>	May	10.4x10 <sup>6</sup>	52.0x10 <sup>6</sup>
June	15.9x10 <sup>6</sup>	79.5x10 <sup>6</sup>	June	5.7x10 <sup>6</sup>	28.5x10 <sup>6</sup>
July	5.9x10 <sup>6</sup>	29.5x10 <sup>6</sup>	July	4.7x10 <sup>6</sup>	23.5x10 <sup>6</sup>
August	23.3x10 <sup>6</sup>	116.5x10 <sup>6</sup>	August	14.1x10 <sup>6</sup>	70.5x10 <sup>6</sup>
September	23.3x10 <sup>6</sup>	85.5x10 <sup>6</sup>	September	23.6x10 <sup>6</sup>	118.0x10 <sup>6</sup>
October	7.6x10 <sup>6</sup>	38.0x10 <sup>6</sup>	October	6.1x10 <sup>6</sup>	30.5x10 <sup>6</sup>

<sup>a</sup>Computed from TI Riverwide Beach Seine Survey data provided to EPA in response dated June 23, 1978.

<sup>b</sup>Minimum abundance estimate divided by gear efficiency adjustment factor of 0.2.

<sup>c</sup>Weighted mean of biweekly population estimates. Weighting factors are the number of days within each biweekly period that fall within a given month.

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## APPENDIX C

## IMPINGEMENT ESTIMATES ASSUMING CLOSED-CYCLE COOLING

The impingement impact estimates for seven Hudson River fish species presented in the main part of this testimony represent historical estimates; that is, we used field and power plant data actually collected during the period 1974-1977 to estimate conditional impingement mortality rates (or exploitation rates). Thus, these rates apply to the case of the power plants operating as they were during that period of time; namely, all units at all power stations used once-through cooling when they operated.

In this appendix we consider three configurations involving cooling towers. Configuration 1 is cooling towers at Indian Point Units 2 and 3, Bowline Units 1 and 2, and Roseton Units 1 and 2. Configuration 2 is cooling towers at Indian Point Units 2 and 3 and Bowline Units 1 and 2. Configuration 3 is cooling towers only at Indian Point Units 2 and 3. For each of these three configurations, the mode of operation and all input data relating to the other power plants (i.e., Lovett, Indian Point Unit 1, Danskammer, and Albany) are assumed to be the same as for the base case of once-through cooling at all power plants.

The three species for which power plant impacts are of greatest concern were selected for this analysis of impingement impact, assuming closed-cycle cooling. The three species are Atlantic tomcod, striped bass, and white perch. Monthly estimates of the number of fish impinged at each power plant were obtained as documented in Appendix A. Only for Indian Point Units 2 and 3, Bowline, and Roseton was it necessary to modify these numbers for the cases involving closed-cycle cooling. The adjustment factors derived by Barnthouse (1979) (Exhibit EPA-205, Table 9), which incorporate consideration of collection efficiency, reimpingement, and impingement survival, were used without modification.

The factors used to adjust from once-through cooling to cooling towers are given in Table C-1. As indicated in footnote a of this table, implicit in the application of this factor is that the number of fish impinged, assuming closed-cycle cooling scales directly in proportion to the ratio of closed-cycle to once-through intake flow.

Table C-1. Factors used to adjust from once-through cooling to cooling towers<sup>a</sup>

Power plant	Months	Total intake flow (gpm)		Factor <sup>c</sup>	
		OT	CC		
Indian Point	Unit 2	April-Nov.	870,000	56,000	0.064368
		Dec.-March	534,000 <sup>e</sup>	56,000	0.104869
	Unit 3	April-Nov.	870,000	61,000	0.070115
		Dec.-March	534,000 <sup>e</sup>	61,000	0.114232
Bowline <sup>d</sup>	all	768,000	16,000	0.020833	
Roseton <sup>d</sup>	all	641,000	16,000 <sup>f</sup>	0.024961	

<sup>a</sup>The factor is applied as follows:

$$N_{ijk} = \text{Factor} \times N_{ijk}$$

where  $N_{ijk}$  is the number of fish of species  $i$  impinged at power plant  $j$  during month  $k$  within the period 1974-1977 with once-through cooling, and  $N_{ijk}$  is the corresponding value if the power plant had been operating with cooling towers.

<sup>b</sup>Source: Table 5.8.1 in Barnthouse et al. 1977.

<sup>c</sup>Calculated as CC total intake flow/OT total intake flow.

<sup>d</sup>Units 1 and 2 combined.

<sup>e</sup>Source: Table V-2 in USNRC 1975. When ambient water temperature at the Indian Point intakes is less than 40 F, the New York Department of Environmental Conservation requires that the condenser water pumps be operated so as to result in the intake flow of new river water being 60% of the normal once-through condenser water flow. For the purposes of this analysis we have assumed that this requirement results in 60% flow during the months of December through March. Service water requirements remain the same for all months, namely, 30,000 gpm at each of Units 2 and 3.

<sup>f</sup>Source: Table A-1 in Exhibit UT-3. Use of this value assumes that all service water is taken from the makeup water.

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CHAPTER IV

ALTERNATIVE SCREENING DEVICES AT INDIAN POINT  
UNITS 2 AND 3, BOWLINE POINT, AND ROSETON GENERATING STATIONS

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## 1. INTRODUCTION

The purpose of this testimony is to evaluate the degree to which impingement and entrainment mortality at the intake screenwells of Indian Point Units 2 and 3, Bowline Point, and Roseton generating stations can be potentially reduced by backfitting them with alternative screening devices. The report entitled "Fish Protection at Steam-Electric Power Plants: Alternative Screening Device" (Cannon et al. 1979) forms the basis of this testimony. It is a generic evaluation of intake structure devices that incorporate fish protection concepts. As an extension of this research activity, for the available data base, we have made an appraisal of the extent to which impingement and entrainment losses at the power plants in question can be potentially mitigated. For each of these activities, Dr. Cada and Dr. Lee were lead biologist and lead engineer, respectively, and Dr. Cannon was project manager.

General site data and descriptions of the existing cooling-water intake systems at Indian Point Units 2 and 3, Roseton, and Bowline Point generating stations are included in Exhibits UT-6, UT-7, UT-9, UT-17, UT-18, EPA-57. Of interest are the orientations of the intake screenwells relative to the Hudson River estuary, the local bathymetry of the estuary, the structural and physical characteristics of the screenwells, the operational mode of the traveling screens, and the species and life stages of fish commonly impinged and/or entrained at these power stations. These data were used to establish the general framework for assessing the engineering feasibility and potential biological effectiveness of backfitting the intake systems with alternative screening devices.

The intake structures of Indian Point Units 2 and 3 and Roseton are located along the shoreline of the Hudson River estuary. The intake structure of Bowline Point is located along Bowline Pond, which connects to the Hudson River estuary. The screenwell of each of these power stations houses conventional vertical traveling screens (VTS) with screen mesh of 3/8-in. square openings. Bar trash racks are located ahead of the traveling screens at Indian Point Unit 3, Roseton and Bowline Point, whereas fixed screens as well as trash racks are located ahead of the traveling screens at Indian Point Unit 2. The screen approach velocity (or flow speed immediately ahead of the screen) for each intake system depends on the pump operational mode and the local depth of the intake water column. At mean water elevation, the average screen approach velocity ranges from 0.54 to 0.95 ft/sec at Indian Point Units 2 and 3, from 0.44 to 0.66 ft/sec at Bowline Point, and from 0.76 to 0.99 ft/sec at Roseton. Except for Roseton, the lower values occur during the winter at reduced flow; at Roseton, the higher value occurs during the winter at reduced flow.

The fish species commonly impinged (those screened out on the existing 2/3-in. mesh screens) and entrained in the condenser system at the subject generating stations include striped bass, white perch, Atlantic tomcod, bay anchovy, alewife, American shad, and blueback herring. The impingement duration for fish impinged during screen rotation varies with the position of fish within the water column but can approach 12 min (assuming a screen travels at a speed of 2.5 ft/min).

These data and other pertinent data in the above referenced documents were used to assess the extent to which impingement and entrainment losses at Indian Point Units 2 and 3, Roseton, and Bowline Point can be potentially mitigated by application of alternative intake screening devices. First, various intake devices incorporating fish protection concepts were selected from the attached report. An engineering evaluation was performed to determine the feasibility of backfitting the alternative design to the existing intake systems at the plants in question and to assess the system reliability with the alternative design from the standpoint of plant operation. To accomplish this task, the following criteria were developed:

1. The technology must have demonstrated performance capability in either a prototype or plant application that requires only site-specific modifications for use on the Hudson River.
2. The reliability of the technology should be established to the point that the continued performance of the cooling system is assured.
3. The technology must be capable of being applied to a once-through cooling system (capacity greater than 641,000 gpm).
4. The technology must be capable of performing in brackish water with medium-to-heavy debris load.
5. Encroachment of the intake structure into the Hudson River should not pose a threat to navigation.
6. The technology should be capable of performing with daily variations in the river stage of 10 ft.
7. The technology must have the capability for retrofitting to the existing intake structure.

Second, for those alternative systems considered feasible as a result of the engineering evaluation, a biological evaluation was performed. The potential biological effectiveness of each system (i.e., for mitigating impingement and entrainment losses) was evaluated by consideration of the available laboratory, prototype, and/or in situ

data for each system within the general framework of the attached report. Striped bass, white perch, Atlantic tomcod, bay anchovy, alewife, American shad, and blueback herring were the species of chief concern for this evaluation.

## 2. SUMMARY AND CONCLUSIONS

Based on the attached report, the following alternative screening devices were evaluated in conjunction with fish return systems for application to the subject Hudson River power plants:

1. conventional VTS modified with fish buckets and auxiliary equipment,
2. center-flow traveling screens,
3. wedge-wire screening systems,
4. flush-mounted and angled horizontal traveling screens, and
5. diversion systems incorporating louvers and angled screens.

These intake designs provide protection for aquatic organisms by functioning either as physical screening devices or as behavioral barriers. Modified VTS, center-flow traveling screens, wedge-wire screening systems, and flush-mounted horizontal traveling screens function exclusively as physical barriers; angled horizontal traveling screens, louver systems, and angled screen systems function as diversion devices. Except for wedge-wire screening systems, which consist of fixed intake screens, the distinction between the two conceptual designs is that the physical screening barriers require impingement of fish for removal from the intake flow, whereas the diversion systems are designed to divert fish from the intake flow by taking advantage of their avoidance behavior.

### 2.1 ENGINEERING EVALUATION

Wedge-wire screening systems and horizontal traveling screens were eliminated from detailed consideration for engineering reasons. These devices are in the developmental stage and are not considered available technologies for application to the subject generating stations. Fish-bucket-type traveling screens and louver and angled screen diversion systems are all deemed feasible technologies for backfitting to the Hudson River intake systems under consideration. The reliability of these technologies from the standpoint of plant operation is not expected to deviate substantially from that of the existing intake systems. Retrofitting the center-flow traveling screens would require extensive modifications to the intake structure and could result in operational problems with respect to pump operation. Because this alternative would offer no real advantage over fish-bucket-type traveling screens with respect to biological effectiveness, a detailed evaluation of center-flow screens is not presented herein.

## 2.2 BIOLOGICAL EVALUATION

The extent to which losses of impingeable life stages of striped bass, white perch, Atlantic tomcod, bay anchovy, alewife, American shad, and blueback herring can be mitigated at the subject power facilities with the application of alternative intake screening devices is presently not amenable to quantitative determination. However, little or no reduction in losses of entrainable life stages would be expected.

We have determined that a screen mesh opening no greater than 15.7 to 19.7 mil (0.4 to 0.5 mm) is necessary to prevent the entrainment of most Hudson River ichthyoplankton. It has not been shown that the survival rates of ichthyoplankton (of the species under consideration) impinged on these fine-mesh screens would exceed those for organisms that are entrained in the cooling system proper. The survival rates of impingeable life stages, however, are expected to be enhanced with the incorporation of the fish-bucket-type system. The degree of increased survival would depend on impingement survival at the existing intakes as well as the species-specific factors. Impinged young-of-the-year white perch and striped bass would be expected to survive at higher rates, but, based on the studies reviewed, the survival of Atlantic tomcod and the more fragile species (such as American shad, bay anchovy, alewife, and blueback herring) would probably not be greatly affected by the incorporation of a fish-bucket-type system.

For the louver and angled screen diversion systems, most of the available data base for the species of concern is limited to laboratory studies and West Coast water diversion projects. Neither of these systems is presently operating at power plant intakes, although some are under construction. Much of the testing was performed for a narrow range of environmental and hydraulic conditions, which did not properly simulate the entire range of conditions likely to be encountered at the sites under consideration. Although some success in diverting larvae has been reported, these diversion systems would probably not reduce entrainment losses of small larvae and fish eggs. Impingeable life stages of the subject species are expected to be diverted, but quantification of the extent of diversion and subsequent survival rates is not currently possible.

The following capital cost estimates for installation of various alternative screening systems at Bowline Point and Indian Point Unit 2 were provided by the Utilities:

Bowline Point - based on completion of construction on 7/1/81 (ref. 7)	
Angled screen diversion system	\$7,632,000
Fish-bucket-type screening system	\$1,743,000

Indian Point Unit 2 - Based on completion of construction on 12/1/78 (ref. 8)

Angled screen diversion system	\$4,985,000
Fish-bucket-type screening system	\$1,955,000

The capital costs of backfitting the Indian Point Unit 3 screenwell with these systems are estimated by the utilities to be comparable to those for Indian Point Unit 2 (Exhibit UT-19), and the capital costs for backfitting at Roseton are judged by the utilities to be of the same order of magnitude as those for Bowline Point (Exhibit UT-16).

### 3. MODIFICATION WITH FISH-BUCKET-TYPE TRAVELING SCREENS

A general description of the various modifications to conventional VTS currently available for possible mitigation of impingement and entrainment losses is given in Sect. 3.1 of the attached report. For the intake systems in question, we have considered (1) the attachment of fish buckets beneath each screen panel, (2) incorporation of a dual-spray wash system for a sequential wash of the screening unit [first, the low-pressure spray (less than 30 psi) for removal of fish; second, the conventional high-pressure spray for debris], (3) general upgrading of the screening unit for continuous operation at screen travel speeds of 2.5 to 10 ft/min for extended periods, and (4) incorporation of a sluiceway system for the return of fish to the Hudson River. These modifications are considered for mitigation of impingement losses. To mitigate entrainment losses, incorporation of fine-mesh screens in conjunction with these modifications is considered.

The capital costs for backfitting fish-bucket-type screening systems at Indian Point Unit 2 and Bowline Point (Glasser 1978) were estimated by the utilities at \$1,955,000 and \$1,743,000 respectively. These costs are based on completion of construction on 12/1/78 for Indian Point Unit 2 and 7/1/81 for Bowline Point. The costs of backfitting this system at Indian Point Unit 3 are estimated by the utilities to be comparable to those for Indian Point Unit 2, and the costs of for backfitting at Roseton are judged by the utilities to be of the same order of magnitude as those for Bowline Point (Exhibit UT-16). The operation and maintenance (O&M) costs and the energy requirements for this alternative screening system are not known, but we would expect them to be much greater than those for the existing intake systems.

#### 3.1 ENGINEERING EVALUATION

Modifications designed to reduce impingement mortality, such as specified above, have been retrofitted to existing intake structures and are presently in operation at the Surry Power Station, Salem Generating Station, and Hanford Generating Project. We have not identified any site or plant design features that would preclude application of this alternative screening system to the Hudson River power plants. These modifications would not alter the intake flow significantly, and, hence, no significant effect on the operation of the circulating-water system would be expected. Because conventional VTS with such modifications do not have an extensive operating history, predictions of system reliability that might affect plant cannot be made with certainty. Of chief concern is the increased maintenance schedule (or screen downtime) required for continuous operation for extended periods and the use of fine-mesh screens (e.g., 0.5-mm openings), which would result in increased screen clogging. The degree of clogging and the manner in which it affects system reliability can be determined only from in situ studies.

In conclusion, we believe that from an engineering perspective such modifications to the existing intakes of the subject plants are feasible. Based on the experience at plants currently using modified traveling screens, some system development after making these modifications may be required to ensure reliable performance.

### 3.2 BIOLOGICAL EVALUATION

Entrainment mitigation. When addressing the entrainment mitigative potential of conventional VTS with modifications as described above, two aspects must be considered: (1) the maximum aperture size of the screen mesh that will effectively filter out (impinge) the ichthyoplankton which would otherwise be entrained, and (2) the postimpingement survival of these fish eggs and larvae, as compared to their postentrainment survival.

The first factor has been discussed at length in Sect. 3.1.2 of the attached report. In general, it appears that mesh sizes no greater than 15.7 to 19.7 mil (0.4 to 0.5 mm) are necessary to prevent entrainment of the majority of fish eggs and larvae of the Hudson River species under consideration. The other factor, postimpingement survival of ichthyoplankton, has been examined for a few species of Hudson River fish. In studies of the impingement concept, with a range of intake velocities including those encountered at the intake systems in question, postimpingement survival has been shown to be inversely related to both impingement duration and approach velocity (Cannon et al. 1979, Sect. 3.1.2). Tomljanovich et al. (1977) found in laboratory tests, for example, that mean 48-hr post test survivals of striped bass larvae were 10% after impingement for 8 min and less than 1% after impingement for 16 min. Similarly, the survival of threadfin shad larvae ranged from 93% after an impingement of 1 min to 20% after an impingement of 16 min.

Thus, survival of ichthyoplankton impinged on fine-mesh screens is species-specific but can be low under conditions of typical intake velocities (0.5 to 1.5 ft/sec) and relatively short impingement durations (16 min or less). The mitigative effectiveness of this modification must be judged by comparing the survival of ichthyoplankton entrained in the condenser system (having passed through the conventional 3/8-in. mesh screens) to that of ichthyoplankton impinged on the fine-mesh screens. Since it has not been demonstrated that postimpingement survival of Hudson River ichthyoplankton would be greater than postentrainment survival at these plants, fine-mesh screens are not considered effective devices for mitigating entrainment losses at these power plants.

Impingement mitigation. Modifications of traveling screens at the power plants in question to reduce only impingement losses would not include replacement of the existing 3/8-in. screen mesh with a finer mesh. Modified intake systems have been the focus of impingement survival studies at both the Surry Power Station and the Salem Nuclear Generating Station.

The fish-bucket-type traveling screens at the Surry Power Station have been in operation since 1974 and were the focus of an 18-month impingement survival study (Cannon et al. 1979). Among the estuarine species impinged at this power plant and also present in the Hudson River are blueback herring, American shad, alewife, bay anchovy, white perch, and striped bass. Although average immediate survival among these species ranged from 82% for bay anchovies to greater than 99% for white perch and striped bass, critical factors such as long-term survival, efficiency of low-pressure sprays in removing fish, and relative proportion of stunned, but living, fish, were not reported. During the initial monitoring phase of modified VTS at the Salem plant (April 18 to May 12, 1977), it was found that the low-pressure spray wash did not remove many of the impinged fish from the screening unit, thereby exposing these fish to the high-pressure spray wash (Cannon et al. 1979, Sect. 3.1.2). The percentage of bay anchovies collected alive and undamaged from the fish sluice trough during this period ranged from 0 to 80 (weighted mean: 33%). Living undamaged white perch and blueback herring accounted for a mean of 73 and 50% respectively of the total numbers of these two species collected in the samples. No latent mortality studies were reported, and survival studies of fish collected in the high-pressure spray wash sluiceway were not performed (Appendix, Sect. 3.1.2).

Impingement survival studies were conducted at the Danskammer Point, Bowline Point, and Roseton generating stations and have been summarized elsewhere (Cannon et al. 1979, Sect. 3.1.2; Exhibit EPA-205). The results, in which postimpingement survival was compared at different modes of operation (continuous vs intermittent) and washwater pressures, were often inconsistent. Continuous rotation generally resulted in better survival among white perch at Bowline Point and Danskammer Point, but not at Roseton. Low-pressure screenwash sprays occasionally resulted in better initial survival of impinged white perch, but often latent survivals between the two spray wash pressures were not significantly different. It was generally observed that postimpingement survival in the laboratory was relatively high for Atlantic tomcod and low for clupeids. No consistent relationships were found between the latent survival of these fish and either screen operational modes or washwater pressures tested.

Thus, the extent of increased survival resulting from these modifications to conventional VTS can be species and site specific, even within the same river systems. Further comparisons will need to be made with more species under a variety of seasonal conditions to quantify the mitigative potential of these modifications.

Fish washed off modified VTS could be returned to the source water body by means of a sluicing system. Important design and operation considerations of this type of fish return system are outlined in Cannon et al. (1973), Sect. 3.7.3. If properly designed (e.g., to account for the potential presences of predators at the fish release sites, tidal influences on reimpingement, or thermal plume entrapment), additional mortality would probably be small.

#### 4. CENTER-FLOW TRAVELING SCREENS

Center-flow traveling screens are currently in operation at the Barney M. Davis Steam Power Station in Corpus Christi, Texas, and have been recently installed at the LaSalle County Generating Station near Joliet, Illinois. The Barney M. Davis station is the only power plant in the United States that uses traveling screens with 19.7-mil (0.5-mm) clear openings.

A detailed description of the center-flow screening system is given in Sect. 3.2 of Cannon et al. (1979). We considered the standard center-flow screening unit with the following modifications for fish protection: (1) sealing the bottom half of each screen basket to form a watertight bucket, and (2) making provisions for the removal of fish from the screening unit ahead of the high-pressure spray wash. The fish return system for this system would be essentially identical to that for the fish-bucket-type traveling screens (Sect. 3.2).

To date, center-flow traveling screens have not been retrofitted to screenbays designed for conventional VTS. Extensive structural modifications would be necessary to retrofit the intake systems in question. Additional structural modifications in the pump well may be necessary to accommodate nonuniformities in the flow generated by the screening unit.

Monthly impingement samples from the center-flow screens at the Barney M. Davis Power Station were taken during 1977 (Cannon et al. 1979, Sect. 3.2.2). Out of a total of 9707 fish collected in these screenwash samples, 86% were classified by the utility as living and undamaged. Although most of the fish impinged were species not found in the Hudson River, 2741 bay anchovies were collected over the twelve-month period. Immediate mortalities among bay anchovies, which had a mean standard length of 1.1 in. (29 mm), ranged from 4 to 98% and averaged 31% over all samples. Latent mortalities were not examined. A lack of comparability in both species assemblages and environmental conditions between the Laguna Madre of the Gulf of Mexico and the Hudson River severely limits any quantitative prediction of entrainment- and impingement-mitigating potential of center-flow screens at Hudson River power plants.

A detailed biological evaluation of center-flow screens is included in Sect. 3.2.2 of Cannon et al. (1979). Like conventional VTS, these screens must impinge fish to remove them from the intake flow. For this reason, we are of the opinion that center-flow screens would conceptually provide a similar potential for protection of fish as do fish-bucket-type screens.

## 5. WEDGE-WIRE SCREENING SYSTEMS

Wedge-wire screens represent a fixed screen design that is presently being considered for application to power plant intakes. One power plant system currently uses the wedge-wire screen, and several power plants will use wedge-wire screens in 1979. A description of this system is given in Sect. 3.4 of Cannon et al. (1979).

It is our opinion that the wedge-wire screening concept for once-through cooling systems is currently in the developmental stage. The application of such an intake system in the Hudson River where the debris loading is medium to heavy would require site-specific studies. Extensive research and development would be necessary to determine the engineering feasibility and potential biological effectiveness of incorporating wedge-wire screening systems at the Hudson River power plants.

## 6. HORIZONTAL TRAVELING SCREENS

A detailed account of the development of horizontal traveling screens (HTS) is given in Sect. 3.3 of Cannon et al. (1979). This alternative intake technology is considered to be in a developmental stage. As yet, HTS have not been employed at cooling-water intakes. Poor mechanical reliability has been the primary concern in the prototype tests. However, recent improvements in the design concept have the potential of providing acceptable mechanical performance for future applications. Because of limited testing, the biological effectiveness of the HTS under a variety of species- and site-specific conditions is unknown.

## 7. LOUVER AND ANGLED SCREEN DIVERSION SYSTEMS

Louver and angled screen diversion systems are behavioral barriers and, as such, are most effective if fish are able to perceive and react to the guiding stimulus associated with them (Cannon et al. 1979, Sect. 3.5). Currently, such fish diversion systems are in operation at several hydroelectric and pumping installations. These systems have not as yet been used at power plant cooling-water intakes; however, a louver system is under construction at the San Onofre Nuclear Generating Station Units 2 and 3, and angled screen systems are under construction at Nine Mile Point Nuclear Station Unit 2 and Oswego Steam Station Unit 6. The diversion systems at these plants are being installed in onshore screenwells that receive water from offshore intakes.

Conceptual intake modifications have been developed that would allow the retrofitting of angled screen diversion systems at Bowline Point (Exhibit EPA-57) and Indian Point Unit 2 (Exhibit UT-17). The utilities estimated that the capital costs of constructing these systems would be \$7,632,000 for Bowline Point (Glasser 1978) and \$4,985,000 for Indian Point Unit 2 (Burke 1978). These costs are based on completion of construction on 12/1/78 for Indian Point Unit 2 and 7/1/81 for Bowline Point. The costs of backfitting this system at Indian Point Unit 2 (Exhibit UT-19), and the costs for backfitting at Roseton are judged by the utilities to be of the same order of magnitude as those for Bowline Point (Exhibit UT-16).

### 7.1 ENGINEERING EVALUATION

Design concepts have been proposed that would allow the retrofitting of louver and angled screen diversion systems to the intake structures of Bowline Point (Exhibit EPA-57) and Indian Point Unit 2 (Exhibit UT-9). It is our belief that such systems can be installed at all of the subject Hudson River power plants without affecting the reliability of the intake screening system to any great extent. The O&M characteristics of these systems would also be expected to be similar to those of the existing intake systems. It is not evident, however, that the required hydraulic conditions or those that were achieved in the Indian Point flume study (Exhibit UT-18) could be duplicated in the field. Because of tidal fluctuations in the Hudson River, the velocity of the approach flow to the diversion device would change periodically, and a uniform approach flow may not be maintained. Prototype laboratory studies would be required to investigate this potential problem.

## 7.2 BIOLOGICAL EVALUATION

Entrainment mitigation. Louver and angled screen diversion systems designed for fish protection as behavioral and not physical screening devices would probably not reduce entrainment losses of fish eggs or small larvae. However, Skinner (1974) reported some success in diverting striped bass larvae with louvers at a large water diversion project in California; diversion efficiencies for fish less than 0.4 in. (10 mm) long were under 35%. Bates and Vinsonhale (1956) achieved a 90% efficiency in diverting striped bass with a mean standard length of 0.7 in. (16.6 mm) [some individuals as small as 0.3 to 0.5 in. (8 to 12 mm)] at a California water project. No survival studies were conducted. The diversion of fish larvae with angled screens has not been reported. Since it has not been demonstrated that diversion and subsequent survival of Hudson River ichthyoplankton at louvers or angled screens would exceed post-entrainment survival, these devices are not considered proving means of mitigating entrainment losses at the Hudson River power plants.

Impingement mitigation. Louver systems have been tested concerning their ability to divert a variety of impingeable fish. Various laboratory and field studies in which these fish were diverted are discussed in Sect. 3.5 of the Appendix. The successful diversion of striped bass at large water diversion facilities on the West Coast was reported by Bates and Vinsonhale (1956) and Skinner (1974). No survival studies were conducted in these tests. However, these striped bass studies occurred between May and September -- months when water temperature and fish swimming speed, a critical parameter in diversion device design, are relatively high. Impingement rates of striped bass (and white perch) on the Hudson River are highest during the colder months, when fish swimming speed is reduced. Therefore, diversion efficiencies determined by the West Coast studies may not be representative of those that may be attained at the Hudson River power plants. Diversion efficiencies ranging from 50 to 98% were reported for Lake Ontario alewives, at test temperatures from about 11°C - 25°C.

In the Indian Point flume study (Exhibit UT-18) louver diversion efficiency tests were conducted with Hudson River white perch, striped bass, Atlantic tomcod, and hatchery-reared striped bass. Diversion efficiencies for river-collected striped bass ranged from 63 to 97% at or above 13°C but dropped to 56% in the single test conducted at 6.2°C. Only tomcod (2 tests total) and hatchery-reared bass (which are larger than native bass) were tested at water temperature below 6.2°C. Efficiencies in these tests ranged from 80 to 99%.

The impingement-reducing potential of angled screens has been examined for several species of Hudson River fish. Diversion efficiencies in excess of 90% were obtained in all angled screen tests in the Indian Point flume study (Exhibit UT-18), but only tomcod (2 tests total) and hatchery-reared striped bass were tested at water temperatures below 11.3°C. Similarly, high diversion efficiencies were obtained in flume studies (Stone and Webster 1977) utilizing alewives and test temperatures of 3.9°C or greater.

Fishes bypassed by angled screens and collected with a lift basket device were held for one week to observe latent mortality (Exhibit UT-18). Mortality attributable to the flume system was reported simply as mortality of test fishes minus the mortality of control fishes, a method which underestimates the true differential mortality when control survival is less than 100%. The more appropriate means of expressing the mortality due to diversion and collection in this flume system is to divide the difference between the test and control mortalities by the control survival. This correction for mortality among control fishes has the effect of increasing the differential mortality and decreasing the total efficiency of the system [diversion efficiency multiplied by  $(1 - \text{differential mortality})$ ]. Control mortalities were generally low in the Indian Point studies (Exhibit UT-18), and thus neither parameter is affected substantially by the correction. On the other hand, high alewife control mortalities (Stone and Webster 1977) result in corrected differential mortalities greater than those reported. The consequent total system efficiencies, which take mortality into account, are significantly lower than the observed diversion efficiencies.

In summary, both louvers and angled screens have been used to divert certain Hudson River fish species in laboratory flume studies. However, these tests, conducted over a limited range of environmental conditions, examined the behavioral responses of only a few species impinged at Roseton, Bowline Point, and Indian Point Units 2 and 3. For example, blueback herring and bay anchovy were not studied, and white perch and Atlantic tomcod were not tested at water temperatures coincident with peak impingement times in the Hudson River (winter and summer months respectively). The presence of debris and high fish densities in the screenwell could result in diversion efficiencies smaller than those suggested by the laboratory tests, which did not adequately consider these factors. The extrapolation of these experimental results to actual power plant installations could be affected by the size of the louvers and angled screens. The Stone and Webster flume studies (Exhibit UT-18, Stone and Webster 1977) utilized single screens less than 13 ft long, and conceptual intake designs consist of a line of louvers or angled screens up to 128 ft long (Bares and Vinsonhaler 1956). It does not seem likely that fish could maintain their position ahead of the louvers or screens long enough to be diverted into a single bypass; thus, multiple bypasses would probably be necessary. Because of these considerations, quantification of the impingement-reducing potential of angled screens and louvers, as compared to the existing intake systems, is not possible.

The use of louvers or angled screens to divert fish into a bypass would require a fish return system utilizing pumps or elevator baskets. Laboratory and in situ studies of collection efficiency and mortality are discussed in Sect. 3.7 of Cannon et al. (1979). Design considerations for the location of fish release sites are discussed in Sect. 3.7.3 of Cannon et al. (1979). Properly designed fish return systems would probably result in low additional mortality.

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CHAPTER V

DENSITY-DEPENDENT GROWTH: A CRITIQUE OF THE  
UTILITIES' "EMPIRICAL EVIDENCE"

TESTIMONY OF

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## SUMMARY

In Exhibits UT-3, UT-4, UT-6, UT-7, UT-49, and UT-50, consultants for the utilities have reported finding inverse correlations between growth and abundance in juvenile striped bass and white perch. The utilities have cited these results as evidence that density-dependent growth, a compensatory mechanism capable of partially offsetting the impact of power plant entrainment and impingement, may be operating in the Hudson River striped bass and white perch populations. Based on my examination of the utilities' past and present attempts to demonstrate the existence of density-dependent growth, I find that the utilities have failed to demonstrate either the existence or the importance of this phenomenon in any Hudson River fish population. The following are my six major conclusions:

- (1) The correlations between striped bass growth and density presented in Exhibits UT-3, UT-4, UT-6, UT-7, and UT-50 have all been invalidated because the availability of new data or the utilities' reevaluation of old data destroyed the correlations that they originally reported.
- (2) The growth data for striped bass and white perch employed in Exhibit UT-50, and the density data for striped bass employed in Exhibit UT-49, contain unevaluated biases that can obscure true relationships and introduce spurious correlations.
- (3) In both Exhibits UT-49 and UT-50 the correlation that is set forth as empirical evidence of density-dependent growth is obtained from a multiple regression in which an environmental variable has been included. Since such variables can be defined in an enormous variety of ways, their use vastly increases the probability of finding correlations that are "statistically significant" (but biologically spurious), if one searches hard enough.
- (4) Each consultant (Texas Instruments, and Lawler, Matusky, and Skelly) has developed its own measures of the growth and density of juvenile striped bass and white perch in the Hudson River. The two sets of indices are, with one exception (white perch growth), either uncorrelated or negatively correlated with each other.
- (5) Causal relationships between growth and density cannot be demonstrated from mere correlations, even if those correlations, unlike those reported by the utilities' consultants, withstand critical scrutiny. In my opinion the utilities' zealous and uncritical search for such correlations, their failure to examine the validity of their data and analytical methods, and their failure to consider alternative explanations (i.e., hypotheses other than density-dependent growth) for their results constitute an improper application of the scientific method.

- (6) Even if the existence of density-dependent growth could be proved, knowledge of its existence would be useless for predictive purposes because its compensatory effects cannot be quantified. Therefore, I argue that the utilities' claims regarding the reality of density-dependent growth, even if they were valid (which they are not), are irrelevant to a rational impact assessment. They should be ignored by the decision-maker.

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## 1. SUMMARY OF UTILITIES' ARGUMENTS

The rationale for the utilities' various attempts to demonstrate the existence of density-dependent growth in the Hudson River striped bass and white perch populations is clearly set forth on page 10.37 of Exhibit UT-4:

Compensatory mechanisms, which allow a population to persist in the presence of exploitation by man, have been observed in many animal populations. Although a compilation of compensatory responses by fish populations appears in Section 10.3, identification and evidence of the existence of one or more compensatory mechanisms in the Hudson River striped bass population is desirable as a rational basis for estimating its compensatory reserve. As Ricker (1975: 277) points out, "An observed correlation gains vastly in acceptability if the implied biological process can be demonstrated to occur, even if only qualitatively," i.e., the demonstration of compensatory processes in this population makes estimation of compensatory reserve more acceptable.

As a means of demonstrating the existence of specific compensatory mechanisms in Hudson River fish populations and justifying their attempts to quantify compensation, the utilities argue that:

- (1) Density-dependent growth is a compensatory process of the type described in the above quote.
- (2) Inverse relationships between density and growth can be empirically demonstrated in two Hudson River fish populations, namely striped bass and white perch.

Descriptions of how density-dependent growth is thought by the utilities to operate as a compensatory mechanism can be found in Exhibits UT-3 (p. 2-IV-52) and UT-49 (p. 8). According to the hypothesis set forth in these exhibits, young fish compete strongly with each other for limited food resources. As the density of fish increases, their rate of growth decreases because less food is available to each fish. This decreased growth leads to increased mortality because the fish remain vulnerable to size-selective predators for an extended period of time. Conversely, as the density of fish decreases (e.g., because of the operation of power plants), the food available to each fish increases, resulting in increased growth, reduced vulnerability to predators, and decreased mortality.

In analyses contained in Exhibits UT-3, UT-4, UT-6, UT-7, UT-49, and UT-50 the utilities have attempted to show that the growth of juvenile striped bass and white perch (Exhibits UT-6, UT-7, and UT-50 only) is inversely related to their abundance. The utilities have nowhere attempted to show that the mortality of juvenile striped bass or white perch is a function of size.

## 2. INTRODUCTION TO MY ANALYSIS

I do not dispute the existence of density-dependent growth as a phenomenon in some fish populations under some circumstances. Beverton and Holt (1957) have argued that density-dependent growth is the most important and easily observable compensatory mechanism in fish that have survived their first year of life. Information pertaining to functional relationships between density and growth in young-of-the-year fish is more limited. In addition to the results reported by the utilities, significant inverse correlations between first-year growth and density have been reported for two other anadromous fish populations in the eastern United States: American shad in the Connecticut River (Marcy and Jacobson, 1976) and white perch in the Patuxent River (Mansueti, 1961). The compensatory effects of density-dependent growth have been documented in trout (LeCren, 1965) and in sockeye salmon (Johnson, 1965).

Because the existence of intraspecific competition, resulting in density-dependent growth, has been documented in a variety of fish species, the possibility that it is occurring in Hudson River fish populations at certain densities in some years in some places cannot be denied out of hand. However, no one has ever argued that growth and density are inversely correlated over all densities in all fish populations. My critical analysis of the utilities' many attempts to find density-dependent growth in the Hudson fails to sustain the utilities' contention that they have demonstrated either the existence or the importance of this phenomenon in Hudson River striped bass or white perch. In addition to demonstrating that the results presented in the utilities' exhibits do not support their conclusions (summarized in Section 1), I show that mere knowledge of the existence or nonexistence of density-dependent growth is of little or no use to the decision-maker. My testimony consists of four parts:

- (1) A history of the many attempts by Texas Instruments and Lawler, Matusky, and Skelly to demonstrate inverse correlations between density and growth in striped bass and white perch (Section 3).
- (2) Critical examinations of the two most recent of these attempts, Exhibits UT-49 and UT-50 (Section 4).
- (3) A discussion of the scientific method and the distinction between correlation and causation (Section 5).
- (4) A demonstration that even if density-dependent growth occurs in the Hudson River striped bass and white perch populations, its compensatory effects cannot be estimated (Section 6).

### 3. A BRIEF HISTORY OF THE SEARCH FOR DENSITY-DEPENDENT GROWTH

Both Texas Instruments (TI) and Lawler, Matusky, and Skelly (LMS) have made several attempts to demonstrate that the growth of juvenile striped bass and white perch in the Hudson River is inversely related to their abundance. All of TI's analyses are based on beach seine data collected by New York University, Raytheon, and TI beginning in 1965. LMS's analyses are derived from bottom trawl data collected by LMS in the Bowline, Lovett, and Roseton-Danskammer vicinities beginning in 1971. In this Section I will briefly trace the history of these attempts. Special attention will be paid to the way in which the generation of new data and the discovery of errors in existing data have forced TI and LMS to abandon old analyses and develop new ones.

The first attempt to demonstrate density-dependent growth in Hudson River fish populations appeared in TI's Multiplant Report (Texas Instruments, 1975). TI developed a juvenile abundance index based on beach seine data collected in the Indian Point vicinity. The data base and method of calculation are described in section V of the Multiplant Report. The estimates of growth used by TI were computed as the mean length of fish captured in August minus the mean length of fish captured in July. TI found that for striped bass, growth and abundance were negatively correlated ( $r = -0.719$ ,  $P < 0.05$ ). When the effects of temperature, measured as "minimal daily mean centigrade surface-water temperature in June" (p. VIII-10), were removed by means of partial correlation, the negative relationship became even stronger ( $r = -0.866$ ,  $p = 0.0117$ ). Interestingly, no relationship between density and growth was found in white perch, either with or without the inclusion of a temperature variable. TI concluded (p. VIII-14) that "growth of individual young-of-the-year striped bass was shown to be negatively density-dependent in the Hudson River population" and that "neither simple nor partial correlation analysis revealed a consistent relationship between individual growth and density of young-of-the-year white perch in the Hudson River."

Exhibit UT-4 contains an analysis of density-dependent growth in striped bass (p. 10.38) that is very similar to the one presented in the Multiplant Report. The growth and abundance data used for this analysis were apparently the same as those used in the earlier report, with two exceptions. A comparison of Figure 10.5-1 of Exhibit UT-4 (Fig. 1) and Figure VIII-4 (Fig. 2) of the Multiplant Report reveals that the original analysis was updated in Exhibit UT-4 by incorporating data collected in 1975. Moreover, the positions of several data points, those for 1969, 1970, and 1974, are considerably different in the later report. The correlation between growth and abundance cited in Exhibit UT-4 ( $r = -0.85$ ,  $P < 0.01$ ) is higher than that cited in the Multiplant Report. Exhibit 4 concludes (p. 10.38) that "this relationship most probably was the result of intraspecific competition among juveniles, which causes numerically larger-than-average year classes of striped bass to experience a smaller increment of growth during the early juvenile stage than numerically smaller year classes."

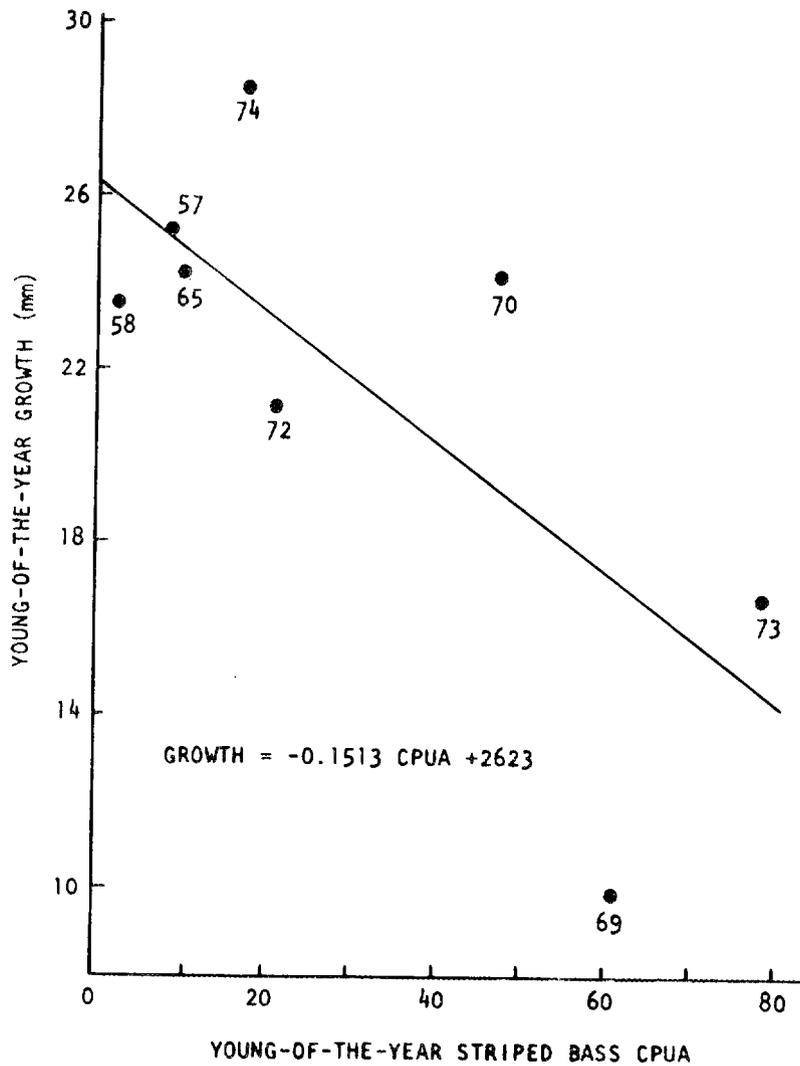


Figure 1. Relationship between growth and abundance of juvenile striped bass, as reported in the Multiplant Report (Texas Instruments 1975, p. VIII-11).

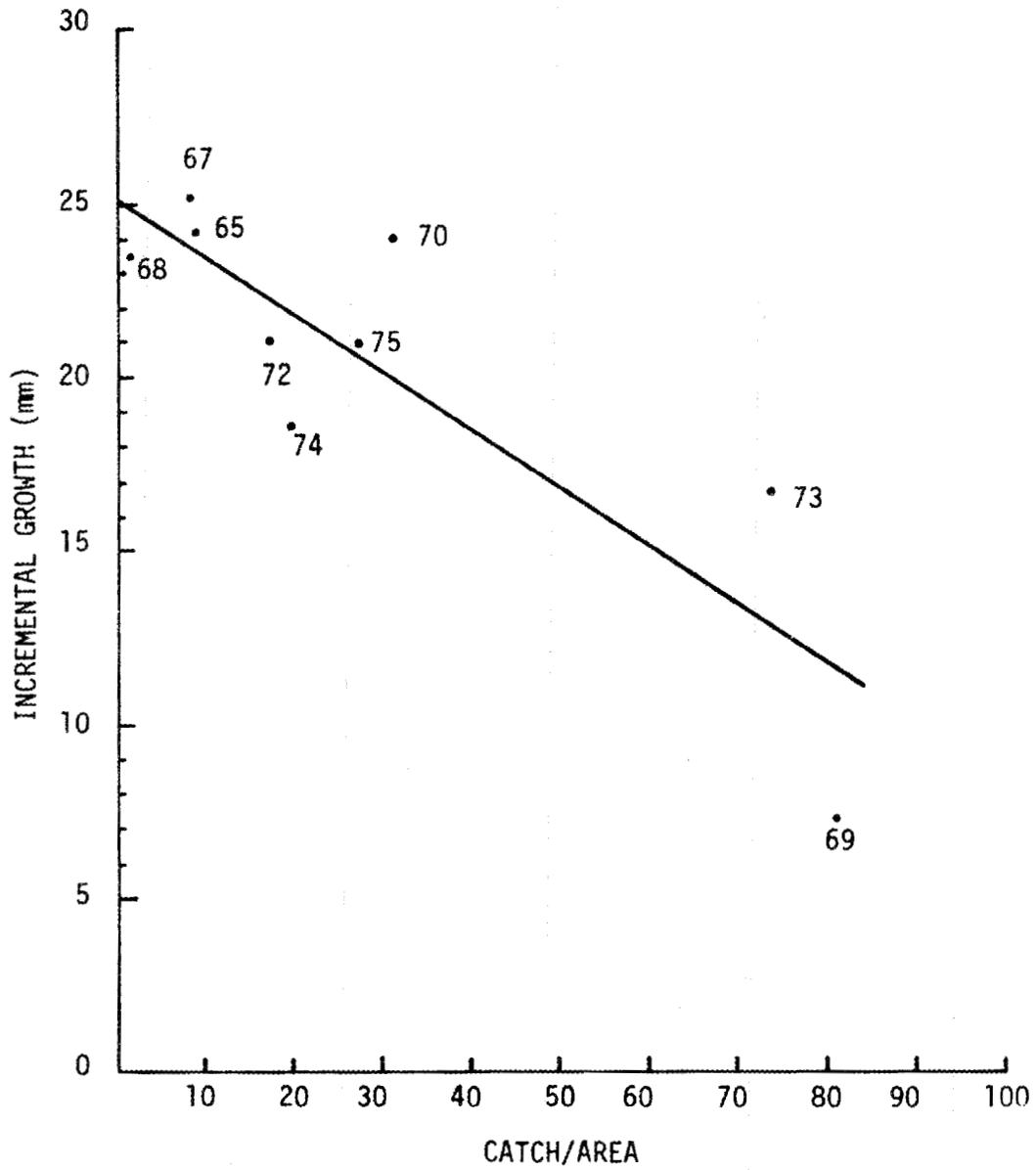


Figure 2. Relationship between growth and abundance of juvenile striped bass, as reported in Exhibit UT-4 (p. 10.39).

Both Exhibit UT-4 and the Multiplant Report concluded that density-dependent growth had been found in striped bass in the Hudson River. However, the analyses upon which this conclusion was based have since been shown to be invalid by the utilities themselves. I here quote page 2-VIII-30 of Exhibit UT-3 in its entirety:

Examination of the raw data inputs to the negative correlation between the juvenile striped bass abundance index and the growth index, based upon beach seine samples taken at Indian Point standard stations (Fig. 10.5.1 of the FRR), revealed some errors which required several changes: (a) the abundance index for 1973 had not included all fish collected. Therefore, the revised CPUA value increased considerably (from 78.8 to 103.4) and, as a result, altered the original negative correlation of  $r = -0.85$ ; (b) the index of growth used in the original correlation presented in the FRR was derived by subtracting the mean total length of all fish collected during July from the mean total length of all fish collected during August. However, since few young striped bass were collected in beach seines prior to mid-July, it was determined that a better estimate of changes in mean total length between July and August would be the mean total length of fish caught during the last half of July. This modification revised the indices of growth and also altered the correlation between abundance and growth; (c) the abundance and growth indices for each year 1965-68 (Indian Point region) were based on a small data base, less than five samples per year. When the revised data were used in a reassessment of the relationship between juvenile striped bass abundance and an index of growth, a significant negative correlation such as was presented earlier in Section 10.5.1 of the FRR no longer emerged. The null hypothesis of a zero correlation cannot be rejected. This, of course, cannot be taken as a positive indication that density and growth are not negatively correlated.

In addition to reporting the errors discovered in TI's data and methodology, Exhibit UT-3 presented a new "demonstration" of density-dependent growth in striped bass. This new analysis was based on bottom trawl data collected by LMS in the Bowline, Lovett, and Roseton-Danskammer vicinities from 1971 through 1975. Rather than the simple regression of growth on density employed by TI, LMS used a multiple regression analysis which also incorporated freshwater flow. LMS computed striped bass density as mean catch-per-unit-effort in trawl samples collected during September, October, and November of each year. The growth variable used by LMS was the mean length of striped bass collected in October. As a measure of flow, LMS calculated the mean June-July Hudson River flow measured at Green Island, New York. LMS found that when this flow variable was included in the analysis, a statistically significant relationship between growth and density appeared. LMS concluded that this relationship suggests the presence of density-dependent growth in juvenile striped bass (p. 2-IV-52).

Exhibits UT-6 and UT-7 contain a similar analysis of density-dependent growth in white perch (analyses in these two Exhibits are identical). The only differences between this white perch analysis and the striped bass analysis in Exhibit UT-3 are:

- (1) Mean length was calculated from fish collected in November rather than in October, and
- (2) Data from 1976 are included in the analysis.

As with striped bass, a significant negative relationship between density and growth was found, when the effects of freshwater flow were taken into account. LMS concluded (Exhibit UT-7, p. 10.1-217; Exhibit UT-6, p. 10.1-153): "Thus, it is possible that, when significant environmental variables are accounted for, a density-dependent, compensatory relationship exists between growth and density for white perch."

Interestingly, both Exhibits UT-6 and UT-7, as originally filed, contained a figure (Fig. 10.1-33 of Exhibit UT-6; Fig. 10.1-48 of Exhibit UT-7) on which were plotted the striped bass density and length values for the years 1971 through 1976 (Fig. 3). It was apparent from this figure that both the density and the length of juvenile striped bass in 1976 were the lowest in the entire period of record. Following a data request by EPA (dated September 27, 1977), the striped bass length and density values for 1976 were provided in a response dated October 17, 1977. When I performed the multiple regression incorporating data from all the years 1971-76, I found no significant relationship. The partial correlation coefficient of growth on density (fixing flow) fell from the significant value of -0.99 excluding 1976 to a far-from-significant -0.26 with 1976 included. The original figures in Exhibits UT-6 and UT-7 were replaced on November 9, 1977 by similar figures from which the 1976 data point had been deleted (Fig. 4).

On February 14, 1978 a new exhibit, Exhibit UT-50, containing yet another analysis of density-dependent growth in striped bass and white perch, was submitted by LMS. This analysis, although similar in concept to the analyses in Exhibits UT-3, UT-6, and UT-7, differed with respect to the density and flow variables used in the multiple regression. The logarithm of density ( $\log D$ ), rather than density itself, was used as an index of abundance. Moreover, in the new analysis the original flow variable (i.e., mean June-July flow) was replaced by a variable (F7) described as the "first principal component score of the monthly mean flows for the months February to August, inclusive" (Exhibit UT-50, p. 5). For both striped bass and white perch, for the years 1971-1976, LMS found significant negative relationships between length and  $\log D$ , once variations due to flow (in the form of F7) were taken into account. This time no claim was made that the existence of density-dependent growth had been demonstrated, only that 96% of the annual variation in striped bass length and 92% of the annual variation in white perch length had been explained by the regressions. This restraint by LMS was admirable and was certainly justified, since as is

GROWTH OF STRIPED BASS  
VS  
RELATIVE DENSITY  
HUDSON RIVER-1971-1976

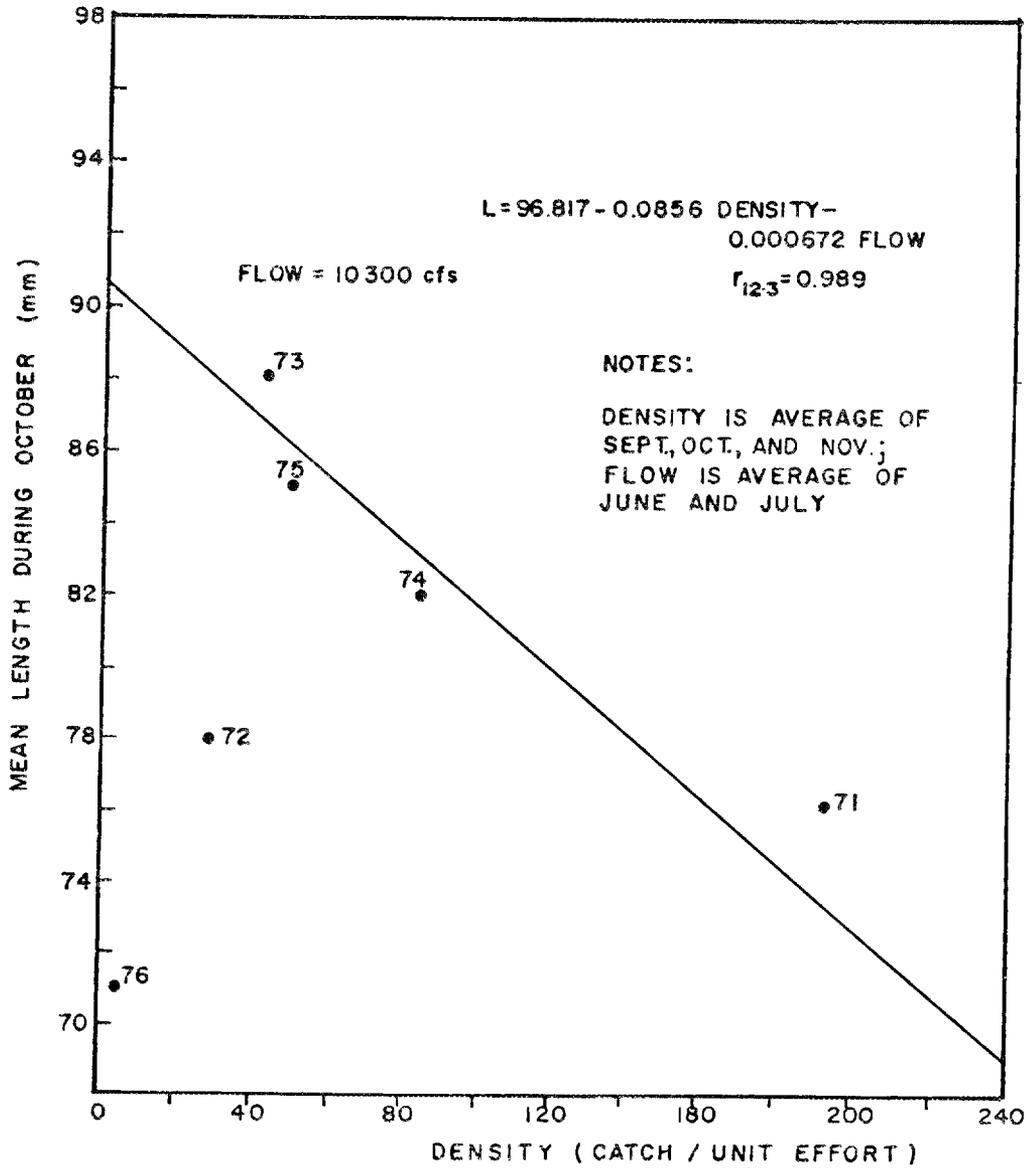


Figure 3. Figure 10.1-33 of Exhibit UT-6, as originally filed.

**GROWTH OF STRIPED BASS  
VS  
RELATIVE DENSITY  
HUDSON RIVER-1971-1975**

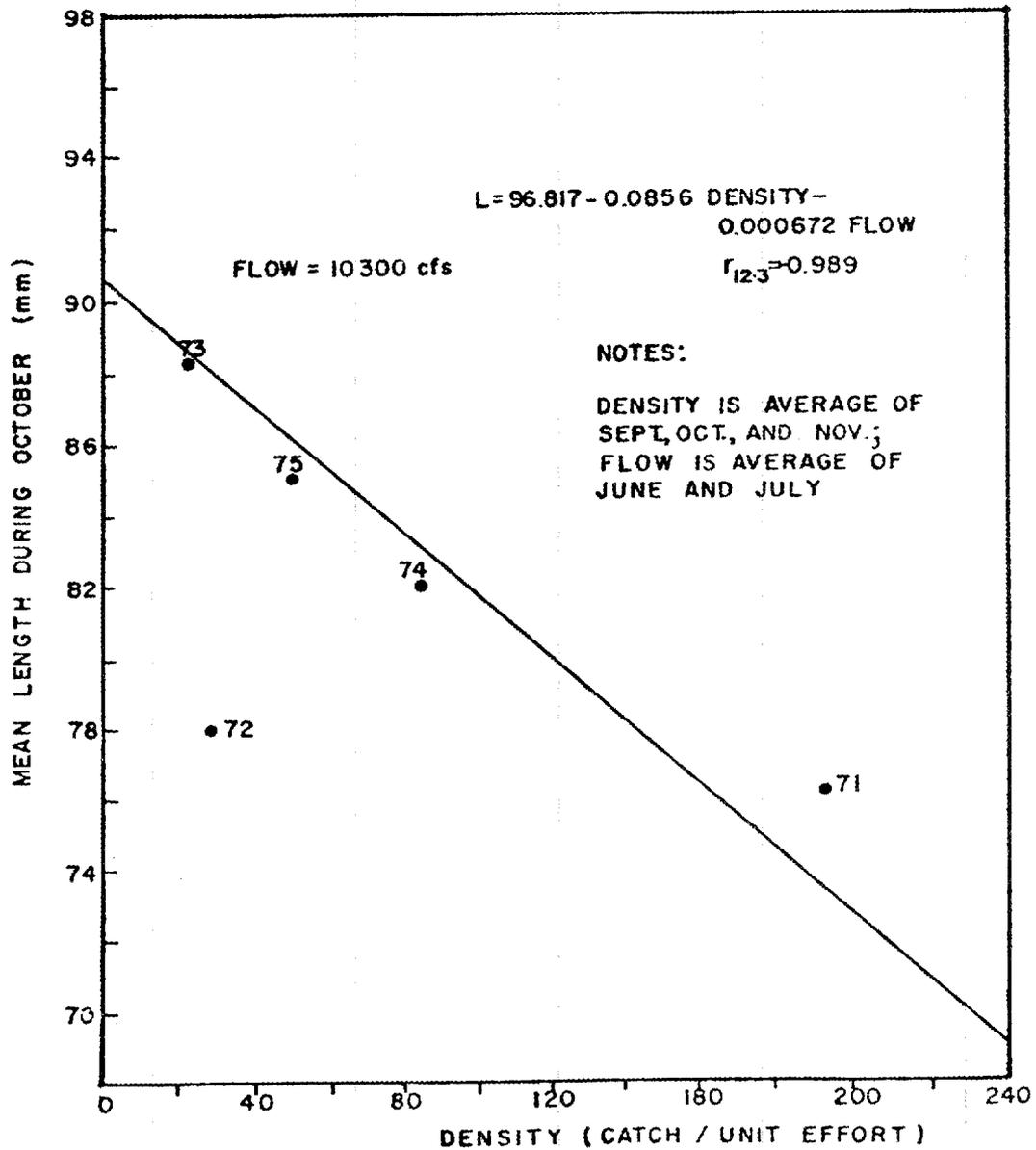


Figure 4. Replacement for Figure 10.1-33 of Exhibit UT-6, filed on 11/9/1977.

discussed in Section IV, when the 1977 data (contained in Exhibit EPA-85) are added to the analysis, the relationships between growth, logD, and F7 disappears for striped bass.

Qualified claims that density-dependent growth "may" have been found in striped bass were made by TI in Exhibit UT-49, filed on February 14, 1978. Unlike TI's previous analyses, this one used riverwide beach seine data, rather than data from the Indian Point vicinity alone. Exhibit UT-49, like Exhibits UT-3, UT-6, UT-7, and UT-50, employed multiple regression in an attempt to remove environmental effects and to reveal a relationship between growth and density. Rather than flow, TI used temperature, specifically the rate of Hudson River temperature increase between 16 and 20 C (termed "degree rise per day") as the environmental variable. TI found significant negative relationships between density and two measures of growth (identified as "incremental growth" and "relative growth"), once temperature effects were accounted for. TI concluded: "The inverse relationship between population density and growth for juvenile striped bass, with temperature effects on growth taken into consideration, offers empirical support for a compensatory mechanism in Hudson River striped bass" (Exhibit UT-49, p. 8).

Section V-C of TI's 1975 Year-Class Report (Texas Instruments 1978a) contains some recent results relating to density-dependent growth in white perch. The methods used in the analysis described in the 1975 year-class report were similar, although not identical, to those used in Exhibit UT-49. A riverwide beach seine density index, analogous to that employed for striped bass in Exhibit UT-49, was used as a measure of white perch abundance. However, an entirely different measure of growth was employed. Rather than the incremental growth and relative growth indices used in Exhibit UT-49, in the 1975 Year Class Report white perch growth was measured as the "daily instantaneous growth rate" during July and August. Two different environmental variables were employed. In addition to temperature (this time measured as the mean Hudson River temperature during July and August), a measure of freshwater flow was used. The results obtained by TI from regressions involving abundance, growth, and either temperature or flow were no different from the results reported in the Multiplant Report: no relationship between the growth and abundance of juvenile white perch was observed.

Thus, beginning in 1975, TI has on three occasions claimed to have found inverse relationships between density and growth in juvenile striped bass. In the Multiplant Report and in Exhibit UT-4 TI made the stronger claim that the existence of density-dependent growth in juvenile striped bass had been demonstrated (this claim is qualified with the word "probably" in Exhibit UT-4). Neither those analyses nor those claims (even with qualifications) have withstood scrutiny. In Exhibit UT-49, TI makes the more circumspect claim that density-dependent growth in juvenile striped bass "may" have been found. On two occasions, first in the Multiplant Report and then again in the 1975 Year Class Report, TI reported finding no relationship between density and growth in juvenile white perch.

Beginning in 1977, LMS has made two attempts to find density-dependent growth in striped bass. The first attempt, reported in Exhibits UT-3, UT-6, and UT-7, failed because the 1976 striped bass data destroyed the correlation that had been found when only the years 1971-75 were considered. As will be shown in Section 4 of my testimony, LMS' second attempt, described in Exhibit UT-50, fails when the 1977 striped bass data are added to the analysis. Although to date neither of LMS' analyses of density-dependent growth in white perch has been invalidated by the addition of new data, I show in section 4.5 that both may be based on an invalid measure of white perch abundance.

#### 4. A CRITICAL EXAMINATION OF EXHIBITS UT-49 AND UT-50

##### 4.1 INTRODUCTION

In this Section I critically examine the two most recent analyses of density-dependent growth in Hudson River fish populations, those contained in Exhibits UT-49 and UT-50. For the moment I have set aside the question of whether either exhibit shows the existence of a causal relationship between density and growth. That topic is taken up in Section 5. Here we are concerned only with statistical correlation: Have the utilities demonstrated the existence of negative correlations (whatever the cause) between growth and abundance in juvenile striped bass and white perch? I believe that they have not. In my evaluation of Exhibits UT-49 and UT-50 I discuss three basic methodological problems common to both exhibits:

- (1) The raw data used in both exhibits contain unevaluated biases that can obscure true relationships and introduce spurious correlations.
- (2) The enormous variety of ways in which variables can be defined vastly increases the probability of finding a "significant" correlation, if one searches hard enough.
- (3) Correlations derived from one set of data cannot be accepted until they have survived the addition of new data.

Finally, I present a comparison of the LMS and TI growth and density indices for striped bass and white perch that throws considerable doubt on the validity of most of the indices (all but the growth indices for white perch) employed by both consultants.

##### 4.2 BIASES CAUSED BY THE ADJUSTMENT OF DATA

The authors of both exhibits were forced to "adjust" some of their data because of differences in sample collection and/or processing methods among years. In LMS' case the problems were caused by the handling of samples rather than by their collection. According to Exhibit UT-50 (p. 3), after collection all fish were identified to species and then counted. The total catch of each species was weighed. However, during the years 1974-76 (1974-75 for white perch), no fish were measured at this time and none were aged. Instead, all samples collected on a given date were pooled, regardless of station or gear type, and random fish were drawn from the pool for measurement. Ideally, in order to perform the analysis presented in Exhibit UT-50, the data used should be (a) the numbers of young-of-the-year fish in the trawl samples, and (b) the lengths of these same fish. However, because of the pooling procedure, these data could not be obtained for striped bass caught in 1974-76 nor for white perch caught in 1974-75. LMS was forced to estimate the numbers of young-of-the-year striped bass and white perch in the bottom trawl samples using regression equations presented on p. 2 of Exhibit UT-50. There was, however, no way for LMS to estimate

the average length of the fish caught in the bottom trawl. Instead, LMS adjusted the data collected in the years when the fish were not pooled prior to measurement. LMS used a weighting scheme (Exhibit UT-50, p. 4) in which the mean length of fish collected with each gear was weighted according to its contribution to the total catch. This procedure is equivalent to pooling the fish prior to measurement.

The pooling procedure would introduce no biases into LMS' analysis if (a) the average lengths of fish collected with each gear were the same, or (b) the distribution of the total catch among the various gears were the same from year to year. But Tables 1 and 2 of Exhibit UT-50 and Tables 1 and 2 of Exhibit EPA-85 clearly demonstrate that neither of these conditions is met. Striped bass and white perch caught by seine in Bowline Pond are on the average smaller than are fish caught by bottom trawl in the river. The contribution of fish from Bowline Pond to the total striped bass catch varied from 0% in 1976 to 17.1% in 1974. The corresponding range for white perch was 0.6% (1971) to 28.6% (1977). Beach seine samples were collected only in Bowline Pond prior to 1975. In 1975-77, beach seine samples were collected in the river as well and accounted for a substantial fraction of the total catch of striped bass: 33% in 1975 and 49% in both 1976 and 1977. Fish caught by beach seine in the river are also smaller than those caught with the bottom trawl (Tables 1 and 2 of Exhibit EPA-85). As is noted in Table 1 of Exhibit EPA-85, the weighted mean length of striped bass in 1977 falls from 76.1 with the river seine samples excluded to 72.0 with all gears included. This 4.1 mm difference is nearly one third as large as the difference (12.6 mm) between the largest and the smallest mean striped bass lengths reported in Exhibit EPA-85 (Table 3).

There is no way to assess the effects on LMS's results of the pooling of fish collected with different gears. The effects of the pooling procedure on the striped bass mean lengths calculated for 1975 and 1976 may have been especially large because of the substantial contribution of fish caught in the river seine samples to the catch in those years. The mean lengths of the fish actually caught with the bottom trawl may have been considerably higher than the mean lengths used in the regression. It is possible that errors introduced by the pooling procedure are simply obscuring the true relationship between density and growth and thus making density-dependent growth more difficult to detect. It is also possible, however, that these errors are introducing a spurious correlation and that in reality no relationship between density, growth, and F7 exists.

In the case of Exhibit UT-49 the problem is not with the length measurements but with the abundance data. Specifically, the beach seine sampling program that provides the data base for TI's analysis was significantly more restricted during the years 1969-1972 than during the other eight years for which data were available. In these three years (no sampling was conducted in 1971) sampling was restricted to the Indian Point vicinity. TI's analysis, however, employs a riverwide index of abundance (we have seen in Section 3 that TI could find no evidence of density-dependent growth in juvenile striped bass when the data was

restricted to the Indian Point vicinity). TI, therefore, used data collected in 1973-75 to construct an "adjustment factor" for converting the Indian Point indices to pseudo-riverwide indices. As is explained in Table 3 of Exhibit UT-49, the adjustment factor was obtained by examining the ratio of riverwide density to Indian Point density during the years 1973-75. The adjustment factor was computed as the geometric mean of the three individual ratios, and then applied to the density indices for 1969-72. Unfortunately, there is so much variation in the ratio of riverwide density/Indian Point density during 1973-75 that very little confidence can be placed in the adjustment factor calculated by TI. To demonstrate this point I have used TI's adjustment factor to adjust the Indian Point density indices presented in footnote (1) to Table 3 of Exhibit UT-49 (Table 1 of this Exhibit). For 1974 the pseudo-riverwide index calculated with TI's adjustment factor is reasonably close to the actual riverwide index, but for both 1973 and 1975 the deviations are quite substantial. For 1973 the pseudo-index is over 60% higher than the actual index; for 1975 it is nearly 50% lower. I conclude from this exercise that the striped bass density indices used by TI for 1969-72 could easily be half as high or twice as high as the values that would have been obtained if a true riverwide sampling program had been conducted in those years.

I have performed the same regression analyses presented in Tables 6 and 7 of Exhibit UT-49, but excluding the years 1969-72. As is shown in Table 2, regardless of whether the incremental growth index or the relative growth index is used, no significant relationship is obtained. Density and temperature together explain only 14-15% of the variance in growth.

The 1969 data are particularly suspect. Not only was the sampling restricted to the Indian Point vicinity, but the sampling effort (Table 3 of Exhibit UT-49) was unusually low. The total area swept in 1969 (60,325 ft<sup>2</sup>) was less than one third that swept in 1972, the year of the second lowest effort, one twentieth of the mean annual effort for the entire period of record (1,166,516 ft<sup>2</sup>), and one sixtieth of the highest sampling effort. As can be seen from Figs. 5 and 6, the 1969 data point is an extremely important one. The density index for this year is the highest, and the growth indices the lowest, of the entire period of record. If the 1969 points are removed from Figs. 5 and 6, no relationship between density and growth is apparent to the eye. When the 1969 data are deleted from the multiple regression (this time retaining 1970 and 1972), the significant correlation between density and growth (either incremental or relative) disappears (Table 2).

#### 4.3 SELECTION OF ENVIRONMENTAL VARIABLES

A second, and perhaps more serious, problem with both Exhibits UT-49 and UT-50 concerns the enormous variety of ways in which variables may be defined. The problem is particularly severe in the case of the environmental variables, i.e., flow and temperature. There is no obviously "right" way to define these variables, as little is known about the mechanisms through

Table 1. Comparison of TI's actual and pseudo-riverwide density indices for juvenile striped bass

Year	Actual riverwide index	Pseudo-riverwide index <sup>a</sup>	% difference <sup>b</sup>
1973	28.60	46.53	+63%
1974	9.50	10.76	+13%
1975	18.30	10.08	-45%

<sup>a</sup>Indian Point density index (Exhibit UT-49, Table 3, footnote 1) multiplied by adjustment factor (0.45). Adjustment factor is geometric mean of individual ratios (riverwide index/Indian Point index) for the years 1973-75.

<sup>b</sup> $100 \times (\text{pseudo-index} - \text{actual index}) / \text{actual index}$ .

Table 2. Recalculation of the regressions described in Tables 6 and 7 of Exhibit UT-49, excluding the years 1969-72 and excluding 1969 only

Excluding 1969-72

Incremental Growth Index<sup>a</sup>

$$\text{Growth} = 19.438 - 0.100 \text{ density}^b + 12.318 \text{ temperature}^c$$

$$R^2 = 0.14 \quad F = 0.42 \quad P = 0.68 \quad (\text{NS})$$

Relative Growth Index<sup>d</sup>

$$\text{Growth} = 0.377 - 0.004 \text{ density} + 0.559 \text{ temperature}$$

$$R^2 = 0.15 \quad F = 0.43 \quad P = 0.68 \quad (\text{NS})$$

Excluding 1969 only

Incremental Growth Index

$$\text{Growth} = 17.411 - 0.193 \text{ density} + 19.937 \text{ temperature}$$

$$R^2 = 0.39 \quad F = 2.26 \quad P = 0.18 \quad (\text{NS})$$

Relative Growth Index

$$\text{Growth} = 0.340 - 0.006 \text{ density} + 0.690 \text{ temperature}$$

$$R^2 = 0.30 \quad F = 1.49 \quad P = 0.29 \quad (\text{NS})$$

<sup>a</sup>Mean length of juvenile striped bass caught in last half of August - mean length of juvenile striped bass caught in last half of July.

<sup>b</sup>Riverwide beach seine density index for striped bass.

<sup>c</sup>Degree rise per day, 16-20°C.

<sup>d</sup>Incremental Growth Index/mean length of juveniles caught in last half of July.

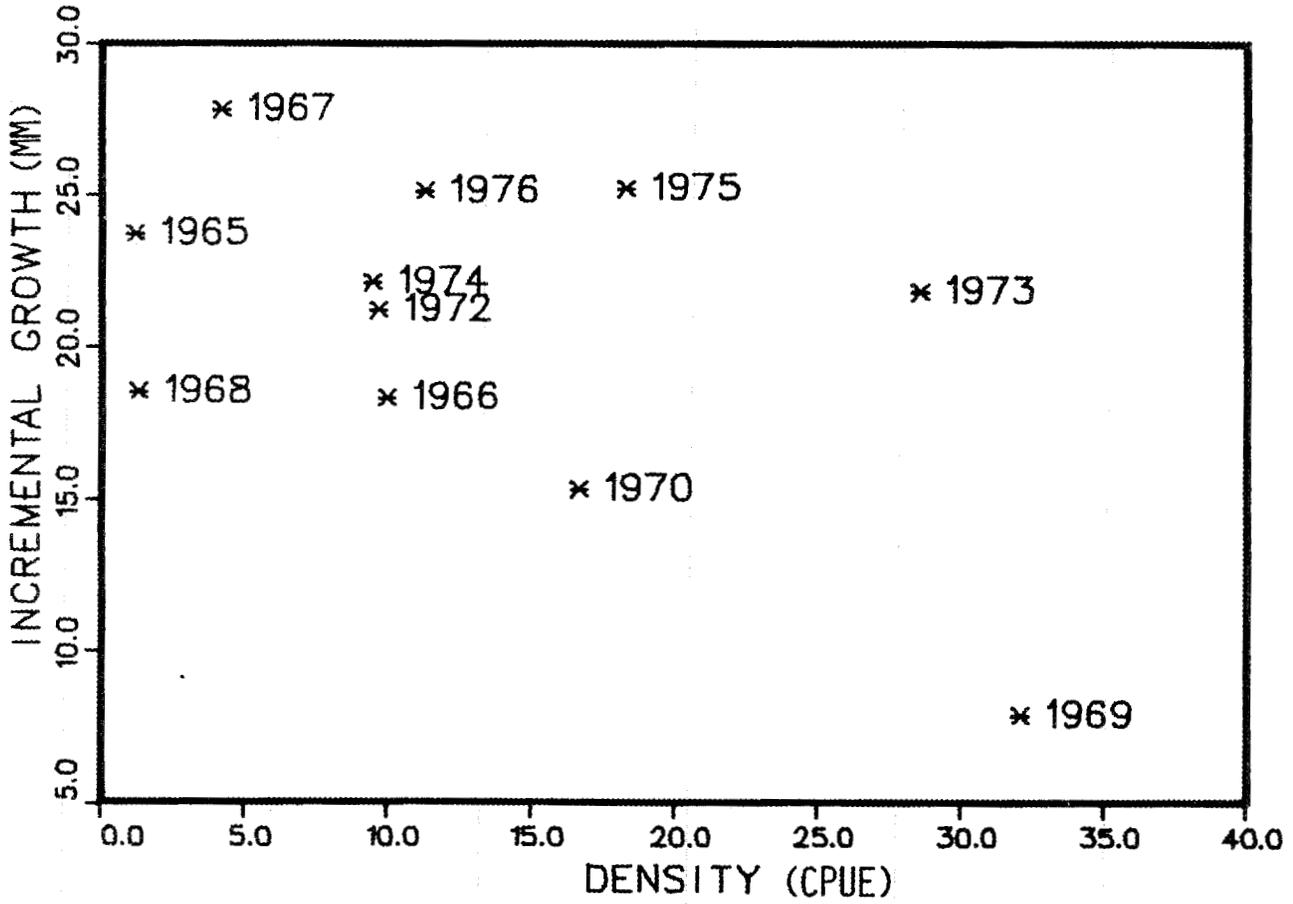


Figure 5. Plot of striped bass density versus incremental growth, 1965-76 (data from Exhibit UT-49).

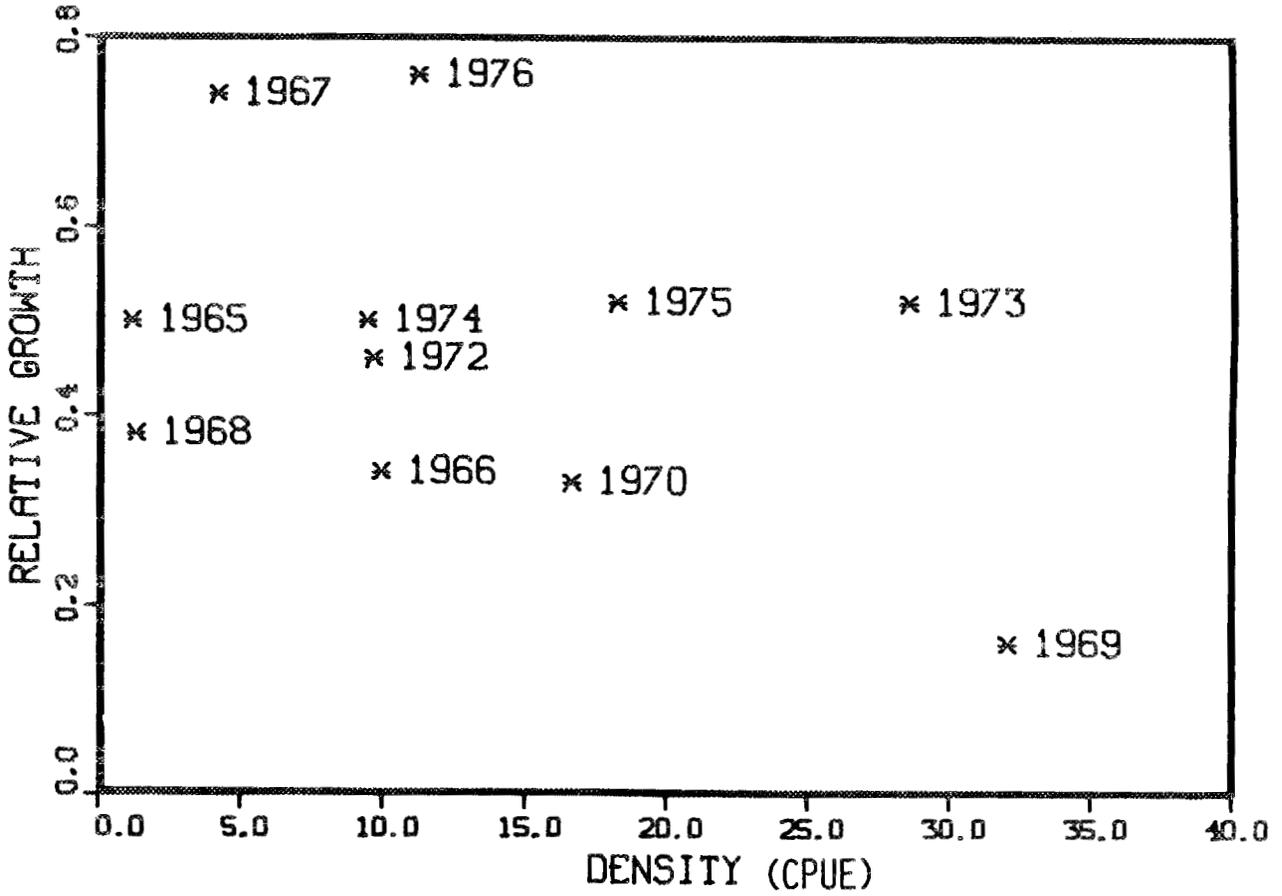


Figure 6. Plot of striped bass density versus relative growth, 1965-76 (data from Exhibit UT-49).

which temperature and flow might influence abundance and growth of striped bass or white perch. Exhibit UT-58 lists 10 different ways of defining freshwater flow. Exhibit UT-49 lists no less than 17 separate water temperature variables. With so many variables to choose from, one can simply try each of them in a regression and then select that which yields the best fit. Mr. Dew of LMS testified (transcript pp. 4167-68) that he did not select the flow variable F7 by this means. However, it is clear from p. 6 of Exhibit UT-49 (quoted below) that TI did in fact try out all 17 temperature variables and did select variables for further analysis based on the strength of their correlation with the growth indices:

Except for degree rise per day, 16-20°C, no other water temperature index was strongly correlated with incremental growth (Table 5), so this temperature index was the only temperature index used in the analysis of population density effects on incremental growth.

Degree rise per day, 16-20°C was also used in the analysis of density versus relative growth, but several other water temperature indices were also relatively strongly associated with relative growth (Table 5). A biological rationale for further selecting temperature indices was lacking; therefore, mean daily temperature for the interval 16 May - 31 August was selected as a second temperature index for incremental growth, since the correlation coefficient was among the highest ( $r = -0.59$ ) and the probability value was the lowest ( $p = 0.056$ ).

With 17 temperature variables to choose from, it is not surprising that TI found two with reasonably high correlations.

Although LMS may not have used TI's "search-and-select" method to choose a flow variable, it is doubtful that LMS would have ceased its attempts to demonstrate a relationship between growth, abundance, and flow had the use of F7 failed to produce a good correlation. It must be remembered that F7 was developed only after the 1976 striped bass data forced LMS to abandon the flow variable used in Exhibit UT-3. In addition, LMS has clearly stated (Exhibit 50, p. 7) that different or even additional variables may be used in future analyses:

Although we are now using F7 as a third variable in order to remove more of the variance observed in mean length at the end of each growing season, this does not mean that the search for more comprehensive and even additional variables will not continue as additional data and degrees of freedom become available.

The newly-available 1977 striped bass data (discussed in Section 4.4) may well provide the stimulus for this search to continue.

#### 4.4 THE EFFECT OF 1977 DATA ON THE REGRESSIONS PRESENTED IN EXHIBIT UT-50

Given the ease with which density, growth, flow, and temperature variables can be constructed, the mere finding of a statistically significant relationship among some set of such variables cannot be taken as proof that a relationship between density, growth, and temperature or flow actually exists. The regressions presented in Exhibits UT-49 and UT-50 at best indicate that such relationships may exist. Further testing is required before they can be accepted as fact. One way of testing the validity of correlations is to add new data to the analysis. For example, it has already been shown that when the 1976 striped bass data are incorporated in the analysis presented in Exhibit UT-3, the inverse relationship between growth and density reported there disappears.

I have found that when the 1977 striped bass data are incorporated into the analysis presented in Exhibit UT-50, the "significant" correlation between growth and density again disappears. Parenthetically, it should be noted that the 1977 striped bass entry in Table 3 of Exhibit EPA-85 (prepared under the auspices of Dr. McFadden as a supplement to Exhibit UT-50, following a request for additional information, Transcript pp. 3855-57) is incorrect. According to Table 1 of the same exhibit, the length index for 1977 that appears in Table 3 is that calculated by excluding fish caught by beach seine in the river. The value calculated with fish from all gears and stations (72.0 mm as opposed to 76.1 mm) is the value that is consistent with the data from other years and is the one that should be used. As is shown in Table 3, when the multiple regression is performed using data from all of the years 1971-77, the correlation virtually disappears. The F statistic for the multiple regression model falls from 36.74 to 0.78, a value that would be exceeded by chance 50% of the time if there were, in fact, no relationship among the three variables. The partial correlation between length and density, fixing flow, is, although slightly positive, essentially zero.

As the 1977 riverwide beach seine data are not yet available, it is not yet possible to test the correlations reported in Exhibit UT-49 in the above way. Interestingly, the white perch analysis in Exhibit UT-50 is not invalidated by the incorporation of the 1977 data. As is shown in Table 4, the multiple regression equation and the partial correlation between length and density remain statistically significant at the 5% level. However, there are three reasons why it is not legitimate to infer from this result that the growth of juvenile white perch is density-dependent:

- (1) The existence of the correlation does not imply that growth and density are in fact causally related. This point will be discussed in Section 5.
- (2) TI has reported no evidence for the existence of density-dependent growth in white perch. Both in the Multiplant Report and in the 1975 Year Class Report TI reported looking for but finding no relationship between density and growth in juvenile white perch.

Table 3. Recalculation of the striped bass regression presented in Exhibit UT-50, incorporating the 1977 data (from Exhibit EPA-85)

Year	Length index	Density index	Flow index
1971	75.6	194.1	0.9836
1972	68.0	31.2	4.3248
1973	84.6	22.7	1.6497
1974	78.6	84.1	0.8988
1975	83.3	50.2	1.0978
1976	72.0	4.4	5.1556
1977	72.0 <sup>a</sup>	8.5	0.3097

$$\text{length} = 78.08 + 0.43 \log(\text{density}) - 1.57 \text{ flow}$$

$$R^2 = 0.28 \quad F = 0.78 \quad P = 0.52 \quad (\text{NS})$$

partial correlation coefficient, length on  $\log(\text{density})$ , fixing flow = 0.09

$$P = 0.86 \quad (\text{NS})$$

<sup>a</sup>Entry in Table 3 of Exhibit EPA-85 (76.1) is incorrect. Correct value obtained from footnote to Table 1 (Exhibit EPA-85).

Table 4. Recalculation of the white perch regression presented in Exhibit UT-50, incorporating the 1977 data (from Exhibit EPA-85)

Year	Length index	Density index	Flow index
1971	66.9	213.5	0.9836
1972	57.1	117.5	4.3248
1973	76.5	38.8	1.6497
1974	69.3	100.4	0.8988
1975	75.7	53.0	1.0978
1976	67.2	45.3	5.1556
1977	74.5	30.1	0.3097

$$\text{length} = 99.95 + 6.07 \log(\text{density}) - 2.27 \text{ flow}$$

$$R^2 = 0.81 \quad F = 8.49 \quad P = 0.04 \quad (\text{significant at } \alpha = 0.05)$$

partial correlation coefficient, length on  $\log(\text{density})$ , fixing flow = 0.82

$$P = 0.05 \quad (\text{significant at } \alpha = 0.05)$$

- (3) Serious doubt exists as to the validity of LMS' density index as a measure of white perch abundance. This point will be pursued in Section 4.5.

#### 4.5 COMPARISON OF GROWTH AND DENSITY INDICES USED IN EXHIBIT UT-49 AND IN THE 1975 YEAR CLASS REPORT TO THOSE USED IN EXHIBIT UT-50

A second, and more powerful, way to test the validity of the analyses in Exhibits UT-49 and UT-50 is to compare them to each other. Both purport to describe the relationship between the growth and abundance of juvenile striped bass in the Hudson River. Since LMS and TI are studying the same population, the growth indices and abundance indices used by these two consultants should be positively correlated with each other. I have found that this is not the case.

Table 5 presents a comparison of TI's incremental and relative growth indices to LMS' growth index over the years 1972-76 (the only years included in both data sets). Both correlations are virtually zero.

Comparison of the two density indices is somewhat more complicated. Whereas TI's index is based on riverwide sampling, LMS's is based solely on data collected at three fixed stations in Haverstraw Bay. LMS has argued in Exhibit UT-50 (pp. 1-2) that juvenile striped bass may be closely associated with a relatively narrow band of water having some preferred salinity. If this is true, then the movement of this band of preferred salinity, which is governed by freshwater flow, may cause striped bass to move into or out of the area sampled by LMS. Thus, freshwater flow may influence LMS' density index by influencing the distribution of striped bass in addition to, or instead of, their abundance. On transcript pp. 4145-4146 Dr. Lawler confirmed that this was the reason for including flow in the regression analysis. Therefore, I performed two comparisons. I first compared the LMS and TI density indices as they appear in Exhibits UT-49 and EPA-85. Second, on the assumption that flow influences striped bass distribution rather than abundance, I used LMS' data to derive an adjusted density index in which the effects of flow (as measured by F7) on density have been removed. To accomplish this I simply performed a linear regression of density on F7 and used the residuals as my adjusted index (Table 6).

Table 7 presents my comparison of TI's riverwide beach seine index to the unadjusted and adjusted LMS bottom trawl indices. There is virtually no correlation between TI's index and the LMS unadjusted index. The TI index and the adjusted LMS index are, in fact, significantly correlated, but the correlation is negative!

Similar comparisons are possible between the growth and density indices for white perch contained in Exhibit UT-50 and the corresponding indices contained in TI's 1975 Year Class Report. Since the LMS and TI data sets for white perch contain only four, rather than five, common years (1972-75), conclusions drawn from these comparisons are necessarily more tentative than are those drawn for striped bass. Nonetheless, the results are relatively

Table 5. Correlations between TI and LMS striped bass growth indices over the period 1972-76

Year	LMS growth (mm) <sup>a</sup>	TI incremental growth (mm) <sup>b</sup>	TI relative growth <sup>b</sup>
1972	68.0	21.2	0.46
1973	84.6	21.8	0.52
1974	78.6	22.1	0.50
1975	83.3	25.2	0.52
1976	72.0	25.1	0.76

LMS vs TI incremental growth

$$TI = 19.74 + 0.04 \text{ LMS}$$

$$r^2 = 0.03 \quad F = 0.08 \quad P = 0.80 \quad (\text{NS})$$

LMS vs TI relative growth

$$TI = 0.830 - 0.004 \text{ LMS}$$

$$r^2 = 0.05 \quad F = 0.15 \quad P = 0.73 \quad (\text{NS})$$

<sup>a</sup>Exhibit EPA-85, Table 3.

<sup>b</sup>Exhibit UT-49, Table 4.

Table 6. Adjustment of LMS striped bass density index to remove effects of flow

Year	Density index	Flow index
1972	31.2	4.3248
1973	22.7	1.6497
1974	84.1	0.8988
1975	50.2	1.0978
1976	4.4	5.1556

Regression of density index on flow

density = 68.8759 - 11.5627 flow

$r^2 = 0.56$      $F = 3.89$      $P = 0.14$  (NS)

Calculation of adjusted index

Year	Observed density	Predicted density	Residual ( = adjusted density)
1972	31.2000	18.8697	12.3303
1973	22.7000	49.8010	-27.1010
1974	84.1000	58.4834	25.6166
1975	50.2000	56.1824	-5.9824
1976	4.4000	9.2635	-4.8635

Table 7. Correlations between LMS and TI striped bass density indices

Year	LMS unadjusted density <sup>a</sup>	LMS adjusted density <sup>b</sup>	TI density <sup>c</sup>
1972	31.2	12.330	9.7
1973	22.7	-27.101	28.6
1974	84.1	25.617	9.5
1975	50.2	-5.982	18.3
1976	4.4	-4.863	11.3

LMS (unadjusted) vs TI

$$\text{LMS} = 53.74 - 0.98 \text{ TI}$$

$$r^2 = 0.07 \quad F = 0.23 \quad P = 0.67 \quad (\text{NS})$$

LMS (adjusted) vs TI

$$\text{LMS} = 33.46 - 2.16 \text{ TI}$$

$$r^2 = 0.78 \quad F = 1051 \quad P = 0.05 \quad (\text{significant at } \alpha = 0.05)$$

$$r = - .88$$

<sup>a</sup>Exhibit EPA-85, Table 3.

<sup>b</sup>This exhibit, Table 6.

<sup>c</sup>Exhibit UT-49, Table 3.

unambiguous. They indicate that the white perch density indices, although perhaps not the growth indices, are as questionable as are the striped bass density indices.

Table 8 contains a comparison between the LMS and TI growth indices for young-of-the-year white perch, for the years 1972 through 1975. The two indices are in fact positively correlated ( $r = + 0.91$ ), although the relationship falls short of statistical significance at the 5% level ( $P = 0.09$ ). As I did for striped bass, I computed a set of adjusted LMS density indices by performing a linear regression of white perch density on flow (Table 9). Table 10 contains my comparisons of TI's beach seine index to the unadjusted and adjusted LMS bottom trawl indices. Neither comparison reveals a positive relationship. TI's index is negatively correlated with both LMS indices; the relationship between the TI index and the unadjusted LMS index is close to being statistically significant at the 5% level ( $r = -0.92$ ,  $P = 0.08$ ).

The finding of strong positive correlations between the sets of growth and abundance indices developed by LMS and TI would have provided strong support for the results and conclusions presented in Exhibits UT-49 and UT-50. The general absence of such correlations (the positive correlation between the growth indices for white perch is the sole exception) casts serious doubt on the validity of the analyses contained in both exhibits. Based on the results presented in Tables 5-10, it appears that at least one of the two striped bass growth indices is an invalid measure of growth in young-of-the-year striped bass, and that at least one of the two density indices is an invalid measure of striped bass year class strength. Similarly, at least one of the two density indices for white perch is probably an invalid measure of white perch year class strength. Since the white perch growth index contained in Exhibit UT-50 is positively correlated with the corresponding index contained in TI's 1975 Year Class Report, it is possible that both are valid measures of the growth of young-of-the-year white perch. However, the results reported in Exhibit UT-50 (i.e., an inverse relationship between white perch growth and density) cannot be valid unless both the growth and density indices are valid.

Table 8. Correlation between TI and LMS white perch growth indices over the period 1972-75

Year	LMS growth (mm) <sup>a</sup>	TI growth (mm/day) <sup>b</sup>
1972	57.1	0.034
1973	76.5	0.0222
1974	69.3	0.0204
1975	75.7	0.0177

$TI = -0.04453 + 0.00086 \text{ LMS}$   
 $r^2 = 0.83 \quad F = 9.64 \quad P = 0.09$

<sup>a</sup>Exhibit EPA 85, Table 3.

<sup>b</sup>1975 Year Class Report (Texas Instruments 1978a), Table B-116.

Table 9. Adjustment of LMS white perch density index to remove effects of flow

Year	Density index (CPUE) <sup>a</sup>	Flow index <sup>a</sup>
1972	117.5	4.3248
1973	38.8	1.6497
1974	100.4	0.8988
1975	53.0	1.0978

## REGRESSION OF DENSITY INDEX ON FLOW

$$\text{density} = 50.1383 + 13.6928 \text{ flow}$$

$$r^2 = 0.34 \quad F = 1.01 \quad P = 0.42 \text{ (NS)}$$

## CALCULATION OF ADJUSTED INDEX

Year	Observed density	Predicted density	Residual (= adjusted density)
1972	117.5000	109.3570	8.1430
1973	38.8000	72.7273	-33.9273
1974	100.4000	62.4454	37.9546
1975	53.0000	65.1703	-12.1703

<sup>a</sup>Exhibit EPA-85, Table 3.

Table 10. Correlations between LMS and TI white perch density indices

Year	LMS unadjusted density (CPUE) <sup>a</sup>	LMS adjusted density (CPUE) <sup>b</sup>	TI density (CPUE) <sup>c</sup>
1972	117.5	8.143	4.3
1973	38.8	-33.927	20.1
1974	100.4	37.955	6.8
1975	53.0	-12.170	26.0

LMS (unadjusted) vs TI

$$\text{LMS} = 124.81 - 3.31 \text{ TI}$$

$$r^2 = 0.85 \quad F = 11.32 \quad P = 0.08$$

LMS (adjusted) vs TI

$$\text{LMS} = 30.86 - 2.16 \text{ TI}$$

$$r^2 = 0.54 \quad F = 2.37 \quad P = 0.26$$

<sup>a</sup>Exhibit EPA-85, Table 3.

<sup>b</sup>This Exhibit, Table 9.

<sup>c</sup>1975 Year Class Report (Texas Instruments 1978a), Table B-116.

## 5. A DISCOURSE ON THE SCIENTIFIC METHOD AND THE DISTINCTION BETWEEN CORRELATION AND CAUSATION

As was shown in Section 3, consultants for the utilities have on five separate occasions reported finding negative correlations between growth and density in Hudson River striped bass. On four of these occasions (the exception is Exhibit UT-50) they have claimed that they had found empirical support for the hypothesis that growth in Hudson River striped bass is an inverse function of density. I dispute this claim not only on the basis of my examination of the individual data bases and regression analyses, but on basic methodological grounds as well.

In the first place, the mere existence of a correlation implies absolutely nothing about causal mechanisms. This simple fact was admitted by Dr. McFadden on transcript page 4162. Inverse correlations between density and growth could be produced by many processes that have nothing whatever to do with density-dependent growth. For example, the LMS bottom trawl data used in Exhibits 3, 6, 7, and 50 are collected during September-December of every year. The time of spawning of both striped bass and white perch, however, varies from year to year. It is possible that variations in the timing of the spawning season could produce an inverse correlation between the density and length of juveniles in the fall. In years in which spawning occurs early, the young fish have an opportunity to feed longer and grow larger before they are sampled. However, the fish are also exposed to predation and other sources of mortality for a longer period of time, and thus their abundance in the fall may be lower. Conversely, when spawning occurs unusually late, juveniles feed and grow for a shorter time before they are sampled by LMS and therefore they may be smaller. But since they are exposed to mortality for a shorter period they may be more abundant. If this, rather than density-dependent growth, were the explanation for the observed negative correlation, then the imposition of power-plant mortality would cause no compensatory increase in growth of the survivors.

The above example is only one of many possible alternative explanations for the results obtained by LMS. An imaginative biologist could undoubtedly formulate similar explanations for the correlation reported by TI in Exhibit UT-49. It simply is not possible to demonstrate a causal relationship between the growth and abundance of striped bass and/or white perch from observational data of the type collected by LMS and TI. Dr. McFadden himself has convincingly documented this point. McFadden (1963) examined the way in which the effects of measurement errors, unmeasured variables, and correlations among variables combine to distort observational data and hide actual causal relationships. Starting from an equation relating the egg production of a laboratory flour beetle (Tribolium confusum) population to temperature and to the density of adult beetles, he constructed a 50-year time series of simulated "field data." He introduced random environmental fluctuations and sampling errors into this data in order to reproduce the low degree of precision that is typically encountered in field studies. When he analysed the time-series in an attempt to

"discover" the relationship between temperature, density and egg production, McFadden found that it was not possible to recover the original equation. Thus, the true causal relationships could not be determined from the simulated "observations."

The relationship, if any, between the growth and density of juvenile fish inhabiting a complex estuarine environment must surely be at least as complex as the relationship between temperature, density, and egg production in laboratory flour beetle populations. It is therefore absurd to suggest, in the absence of any but the most rudimentary knowledge of the biotic and abiotic determinants of the growth of juvenile striped bass and white perch, that the existence of a causal relationship between growth and density can be inferred from a correlation derived from six (Exhibit UT-50) to eleven (Exhibit UT-49) years of observational data. No such inference could be drawn even if the correlations presented in these two exhibits had withstood the critical examination described in Section 4 of this testimony.

The utilities' consultants might claim that, although they have not proven that the growth of juvenile striped bass and/or white perch is density-dependent, they have found "empirical support" for this hypothesis. I find this argument to be equally absurd. The essence of the scientific method, as described by Karl Popper (1934), is not the proving of hypotheses, but the falsifying of hypotheses. Having proposed an hypothesis (e.g., that the growth of juvenile striped bass is an inverse function of their abundance), a scientist does not stubbornly defend it by searching for data that supports his hypothesis, explaining away contradictory data and ignoring alternative hypotheses. Instead, he attacks his hypothesis by designing and conducting rigorous tests intended to prove it wrong. An hypothesis earns our belief not when we have searched for and found some evidence to support it, but when we have rigorously tried to disprove it and failed.

Judged by Popper's standard, the utilities' persistent, uncritical attempts to demonstrate the existence of density-dependent growth in Hudson River fish populations are a bizarre perversion of the scientific method. Neither TI nor LMS has ever discussed any possible interpretation of their results other than the hypothesis of density-dependent growth. LMS has either implied that the existence of density-dependent growth has been demonstrated, (e.g., "Information on behavior in the first year of life suggests strongly that growth rate increases as population decreases" (Exhibit 3, p. 2-IV-51)) or stated that it is "possible" that density-dependent growth exists (Exhibit UT-6, p. 10.1-153; Exhibit UT-7, p. 10.1-217). TI has consistently claimed that the existence of density-dependent growth has been demonstrated (Multiplant Report, p. VIII-14), "probably" has been demonstrated (Exhibit UT-4, p. 10.38) or "may" have been demonstrated (Exhibit UT-49, p. 8). Even when reporting the lack of a significant correlation between density and growth, TI was careful to remind the reader that

"This, of course, cannot be taken as a positive indication that density and growth are not negatively correlated" (Exhibit UT-3, p. 2-VIII-30).

Both TI and LMS have been remarkably uncritical of their own data and methods. Nowhere in any of the utilities' exhibits is it possible to find a discussion of biases in the growth or density indices that might make them unsuitable as measures of growth or abundance. Nowhere is there a discussion of sampling error and how it might influence the results of the analyses. Nowhere are any attempts made to compare LMS' indices to TI's as a check on their reliability. When one analysis is abandoned because of uncooperative new data or a reevaluation of old data, it is simply replaced by a new analysis, using new variables, yielding the same result: an inverse correlation between growth and density is "discovered" and cited as providing empirical support for the existence of density-dependent growth.

The correlations offered by LMS and TI are the starting point, not the end point, of a valid scientific analysis of the relationship between growth and abundance in Hudson River striped bass and white perch. The raw data and the indices derived from the data must be critically examined. Causal mechanisms through which flow or temperature could influence the growth and abundance indices in a way consistent with the results must be formulated and then critically examined. Alternative explanations for the results must be considered, and rigorous tests must be devised by which as many as possible of the competing hypotheses (including that of density-dependent growth) can be falsified. Additional data, when it becomes available, must be used as a basis for still more rigorous testing. Only when the hypothesis that increases in striped bass or white perch abundance cause growth to decrease has survived vigorous and repeated attempts to disprove it can it properly be said that empirical support has been found for it.

In Exhibit UT-50 (p. 7) LMS suggests (with a quote from the well-known biometry textbook by Sokal and Rohlf) that the mere search for environmental variables that "remove" variance in the growth index, thus revealing the relationship between density and growth, is "analogous to the fundamental process of science." Mr. Dew repeats and expands upon this assertion on transcript p. 4148. I emphatically disagree (as does Dr. Rohlf, on p. 4 Exhibit EPA-208), and I close this section with a quote of my own (Popper, 1934: p. 281, emphasis is Popper's):

The wrong view of science betrays itself in the craving to be right; for it is not his possession of knowledge, of irrefutable truth, that makes the man of science, but his persistent and recklessly critical quest for truth.

6. A DEMONSTRATION THAT THE COMPENSATORY EFFECTS OF DENSITY-DEPENDENT GROWTH, ASSUMING THAT IT DOES OCCUR, CANNOT BE ESTIMATED

If density-dependent growth exists, are its effects sufficient to protect populations from impact? I believe that this question cannot be answered from the data presented by the utilities, even if the results described in Exhibits UT-49 and UT-50 are accepted as fact. Suppose, for the moment, that the regression equations presented in these two Exhibits accurately describe the relationship between growth and abundance in Hudson River striped bass and white perch. I have used these equations to predict the change in length of juvenile striped bass and white perch that would result from reductions in abundance of 20% and 50%. As base values I chose the median values of density (Exhibit EPA-85, Table 3; Exhibit UT-49, Table 3), flow (Exhibit EPA-85, Table 3), and temperature (p. 1 of handwritten notes submitted by Dr. Klauda of TI on December 16, 1977, Transcript pp. 1092-93) presented by LMS and TI.

From the regression equations in Tables 6 and 7 of Exhibit 49, I calculated the expected incremental and relative growth of striped bass at densities equal to 1.0, 0.8, and 0.5 times the base value. I then used the results to calculate the expected length at the end of August of a striped bass that was 46.8 mm, long (the median value in Table 4 of Exhibit UT-49) in July. Similarly, from the regression equations in Tables 3 and 4 of Exhibit UT-50, I calculated the expected end-of-season length of striped bass and white perch at densities of 1.0, 0.8, and 0.5 times the base values. The results of these calculations are presented in Table 11. The equations in both Exhibits UT-49 and UT-50 predict that a 20% reduction in striped bass density would result in a relative increase in striped bass length of less than 1.5%. A 50% reduction in density would result in less than a 5% relative increase in striped bass length. For white perch, the changes predicted by Exhibit UT-50 are slightly larger: 2.8% for a 20% reduction and 8.4% for a 50% reduction.

Given the small changes in length (2-4 mm for striped bass and 6 mm for white perch, assuming a 50% reduction) that would result from even large reductions in abundance, it is tempting to conclude that compensation due to density-dependent growth could not possibly offset any substantial power plant impacts. But depending on the exact relationship between size and mortality, a small increase in the length of a fish could result in either a negligible or a substantial increase in its probability of survival. If a 1% increase in the size of a fish increased its daily probability of survival by 1% (i.e., from  $s$  to  $1.01s$ ), its probability of surviving through the next month would be increased by a factor of 1.35 ( $1.01^{30}$ ). If its daily probability of survival were increased by only 0.1%, it would be only 1.03 times as likely to survive through the next month. No data exists pertaining to the size-mortality relationship in either striped bass or white perch (Dr. Lauer of Ecological Analysts suggests, on transcript pp. 8782-84, that larvae growing at different rates may in fact have the same survival rate). Therefore, it is not possible to estimate the amount

Table 11. Increase in striped bass and white perch growth caused by 20% and by 50% cropping, assuming that regression equations in Exhibits UT-49 and UT-50 are valid

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STRIPED BASS (Exhibit UT-49)

Median degree rise/day 16-20 C:  $T = 0.308$   
 Median density last half of July (CPUE):  $D = 10.5$   
 Median length of fish (mm):  $L_J = 46.8$   
 Incremental growth:  $G = 16.469 - 0.345 D + 26.885 T$   
 Relative growth:  $G = 0.323 - 0.009 D + 0.818 T$

	<u>G1.0D</u>	<u>L1.0D</u>	<u>G0.8D</u>	<u>L0.8D</u>	<u>G0.5D</u>	<u>L0.5D</u>
Incremental growth	21.1	67.9 <sup>a</sup>	21.9	68.7 <sup>a</sup>	22.9	69.4 <sup>a</sup>
Relative growth	0.48	69.3 <sup>b</sup>	0.50	70.2 <sup>b</sup>	0.53	71.6 <sup>b</sup>

% change relative to base case (1.0D)

	<u>0.8D</u>	<u>0.5D</u>
Incremental growth	+1.2%	+2.7%
Relative growth	+1.3%	+3.3%

STRIPED BASS (Exhibit UT-50)

Median flow index:  $F = 1.6497$   
 Median fall density (CPUE):  $D = 50.2$   
 Length:  $L = 109.344 - 5.3667 \log(D) - 5.5077 F$

	<u>L1.0D</u>	<u>L0.8D</u>	<u>L0.5D</u>
Length	79.2	80.4	83.0

% change relative to base case (1.0D)

	<u>0.8D</u>	<u>0.5D</u>
Length	+1.5%	+4.8%

WHITE PERCH (Exhibit UT-50)

Median flow index:  $F = 1.6497$   
 Median fall density (CPUE):  $D = 100.4$   
 Length:  $L = 111.935 - 8.132 \log(D) - 2.9264 F$

	<u>L1.0D</u>	<u>L0.8D</u>	<u>L0.5D</u>
Length	68.8	70.7	74.6

% change relative to base case (1.0D)

	<u>0.8D</u>	<u>0.5D</u>
Length	+2.8%	+8.4%

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<sup>a</sup>  $L = L_J + G$  (incremental).

<sup>b</sup>  $L = L_J + L_J \times G$  (relative).

of power plant mortality that might be offset by density-dependent growth. Given the difficulty of estimating mortality rates for whole populations, and the low precision of the results that are generally obtained, I doubt that useful size-specific mortality rates can ever be obtained.

## 7. CONCLUSIONS

I conclude that utility Exhibits UT-3, UT-4, UT-7, UT-49, and UT-50 do not demonstrate in any scientifically valid manner the reality of density-dependent growth as a compensatory mechanism regularly operating in juvenile striped bass and/or white perch.

I find the utilities' past and present arguments for the existence of density-dependent growth in striped bass to be totally unconvincing. On five occasions beginning in 1975 utility consultants have attempted to demonstrate inverse correlations between growth and abundance in striped bass. Four of the five attempts have since been invalidated because either the availability of new data or a reevaluation of the old data destroyed the correlations that were originally reported. Although LMS has twice reported finding similar inverse correlations between growth and abundance in white perch, TI has twice reported looking for but finding no such correlations.

An examination of the two most recent analyses, those presented in Exhibits UT-49 and UT-50, reveals serious deficiencies in both. The length data used by LMS (Exhibit UT-50) contains unevaluated biases caused by the pooling of fish collected from different stations with different gears. TI's "riverwide" density indices for the years 1969-72 (Exhibit UT-49) are in actuality Indian Point vicinity indices that have been converted to pseudo-riverwide indices using a highly questionable "adjustment factor." The correlations found by TI are critically dependent on the 1969 data, which, in addition to being "adjusted," were obtained from an extremely limited sampling program. It is quite possible that the results reported in both exhibits are no more than artifacts introduced by the pooling and adjustment procedures.

In both exhibits the correlation that is set forth as empirical evidence of density-dependent growth is obtained from a multiple regression in which an environmental variable (temperature in Exhibit UT-49, freshwater flow in Exhibit UT-50) has been included. In each case, the particular variable selected was chosen from a large number of alternative formulations at least partly because a good fit could be obtained with it. I believe that, aside from any problems with the growth and density indices, results derived in this way cannot be accepted as empirical support for the reality of density-dependent growth.

My comparisons of the TI and LMS growth and abundance indices for striped bass and white perch are the strongest evidence that the correlations presented in Exhibits UT-49 and UT-50 are spurious. Both sets of indices purport to be measures of the abundance and growth of juvenile striped bass and white perch in the Hudson River. However, when the LMS and TI indices for the same years are compared, in only one case (white perch growth) is there a positive correlation between LMS's indices and those of TI. The measure of striped bass growth employed by LMS in Exhibit UT-50 is uncorrelated with the corresponding measure employed by TI in Exhibit UT-49.

Depending on whether or not LMS's bottom trawl density indices for striped bass and white perch are adjusted to remove the effects of flow, they are either uncorrelated or negatively correlated with TI's beach seine density indices. These results clearly show that at least one of the two striped bass growth indices is an invalid measure of the growth of juvenile striped bass. They also show that either LMS's bottom trawl indices, TI's beach seine indices, or both are invalid as measures of the abundance of juvenile striped bass and white perch.

I do not believe that the utilities' zealous search for correlations that support the hypothesis of density-dependent growth is a proper application of the scientific method. Causal relationships between growth and density cannot be demonstrated from mere correlations, even if those correlations, unlike those reported by LMS and TI, withstand critical scrutiny. More important, a proper scientific analysis must include a critical examination of the growth and density indices in order to determine whether they really measure growth and density. The utilities' consultants have clearly failed to perform such an examination. Alternative explanations for the observed correlations must be considered, and independent tests of these explanations must be devised. The utilities' consultants have never reported considering any hypothesis other than density-dependent growth as a possible explanation for the correlations they have found, lost, and found again.

Finally, I conclude that the existence or non-existence of density-dependent growth is entirely irrelevant to a rational assessment of the impact of power plants on the Hudson River striped bass and white perch populations. I do not dispute the existence of some form (or forms) of compensatory mechanisms in these populations under certain conditions. Once this is conceded, the mere demonstration that some particular mechanism exists or does not exist is useless for predictive purposes. Studies of density-dependent growth would be useful if it were possible to quantify its compensatory effects. But, as I have shown, these effects cannot be quantified (they could be either substantial or negligible) in the absence of precise quantitative information on the relationship between size and mortality in juvenile fish. No such information now exists and I doubt that it can ever be obtained. In my opinion, only those facts that can contribute to a rational impact assessment should be considered by the decision-maker. Therefore, I believe that all arguments for the existence of density-dependent growth are irrelevant and should be ignored.

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CHAPTER VI

A CRITICAL REVIEW OF THE UTILITIES' AGE COMPOSITION ANALYSIS  
OF THE HUDSON RIVER STRIPED BASS POPULATION

JOINT TESTIMONY OF

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## 1. INTRODUCTION

Page 2-VIII-1 of Exhibit UT-3 states,

"During 1976, Hudson River striped bass of spawning age were sampled more intensively than ever before in order to obtain estimates of age composition, sex ratio, age at sexual maturity, fecundity, egg production, and other factors."

Page 2-VIII-3 of Exhibit UT-3 states,

"The most important immediate application of the 1976 data is to indicate the most realistic time lags between parental spawning and spawning by progeny generations as a basis for the stock-recruitment analyses in Section 2-IV. The relevant statistics are the percentages of annual egg production contributed by each age group. These are calculated here from estimates of age composition, sex ratio, age at maturity, and fecundity."

The utilities' choices of lag times, which determine the pairing of indices of stock and recruitment in the utilities' Ricker stock-recruitment curve-fitting exercise (e.g., Section 2-IV-B of Exhibit UT-3) are very important in the context of their method of power plant impact assessment. Different time lags result in different estimates of alpha, a parameter of the Ricker model. Alpha is also one of the two parameters of the utilities' equilibrium reduction equation (the other being the power plant total conditional mortality rate; Section 2-V of Exhibit UT-3). The equilibrium reduction equation is used by the utilities to predict long-term power plant impact on the striped bass population, as well as on other fish populations of the Hudson River, and is derived from the Ricker stock-recruitment model (Section 2-VI and 2-VII of Exhibit UT-3). The sensitivity of the utilities' long-term impact prediction to changes in the value of alpha is shown in Figure 2-V-1 of Exhibit UT-3. For example, on page 2-IV-28 of Exhibit UT-3, it is indicated that going from a lag time of 5 years to 6 years, the estimate of alpha decreases from 5.4 to 2.7. At a total conditional mortality rate of 0.2, for example, the long-term population reduction increases from 13 to 22 percent as alpha goes from 5.4 to 2.7.

In addition, the choice of lag times and the corresponding estimates of alpha contained in Exhibit UT-58 also depend on the utilities' determination of female age composition in 1976. Thus, the validity of their choice of lag times in Exhibit UT-58 also depends on the validity of their age composition analysis. The first purpose of this testimony is to determine the validity of that analysis. If the analysis is found invalid, the second purpose of this testimony is to present a more valid age composition determination, but only if such a determination is warranted by the data.

## 2. DESCRIPTION OF THE UTILITIES' AGE COMPOSITION ANALYSIS

Section 2-VIII-C of Exhibit UT-3 (pages 2-VIII-7 to 2-VIII-9), which is entitled "Sex Ratio And Age Composition," describes the methodology and results of the utilities' 1976 adult striped bass sampling program as it pertains to age composition. The description regarding methodology is brief. Page 2-VIII-7 states,

"Fish were collected with haul seines and with gill nets. The haul seine data, which are relatively unbiased, were used both directly to estimate sex ratio and age composition, and to correct for the size-selective gill net data...".

Page 2-VIII-8 states,

"Age composition data based on haul seine catches present a pattern different from combined gear (adjusted gill net data)...".

With possession of only the utilities' testimony filed on July 11, 1977, in particular Exhibit UT-3, EPA and its consultants had in their possession the following knowledge: the utilities had made estimates of age composition (1) from catches of unknown numbers of striped bass, made by a haul seine of unknown size(s), deployed in an unknown region(s) of the Hudson River, and (2) from catches of unknown numbers of striped bass, made by an unknown number of gill nets, of unknown mesh size(s), deployed in an unknown location(s) in the river, with the added fact (3) that these gill net catches were adjusted in some unknown manner by the catches of the haul seine(s).

However, Mr. McLaren, the utilities' primary witness with respect to the subject, testified that the methodology for determining age composition was very complex (Tr. 2823). Because of its complexity, we believe that if the utilities adhered to sound scientific practice, a separate report or appendix would have been prepared and filed with Exhibit UT-3.

A detailed and accurate description of the utilities' sampling program, data analysis and analysis rationale was obtained by April 20, 1978, approximately 8 months after Exhibit UT-3 was filed (July 11, 1977). The history which led to the obtaining of the detailed and accurate description is set forth below:

1. Utility response, dated August 23, 1977, from Dr. Marcellus to Henry Gluckstern, to Question 2 of a June 28, 1977 letter from Henry Gluckstern to Dr. Marcellus.

This response, in providing data defining the age composition of the striped bass spawning stock in the Hudson River, indicated that age composition was determined every two weeks above and below RM 38. The mean of these biweekly and regional determinations was included in the

testimony, and represented the utilities' best estimate of the age composition of the striped bass population (Table 2-VIII-4 of Exhibit UT-3). A reference was then made for the first time to what would be later known as the "4 fish minimum rule." The utilities indicated that they required that a minimum of 4 fish within an age group had to have been collected within a particular region and time interval before a sex ratio was determined. If there were fewer than 4 fish collected within an age group, these fish were not included in the age composition analysis. As will be shown below, the utilities' statement in this response, regarding the operation of the "4 fish minimum rule," was erroneous.

2. Utility submittal of September 26, 1977, in response to questions posed by EPA and its consultants at the first technical meeting between EPA's technical consultants and the utilities' technical consultants at Peekskill, New York on September 26-27, 1977. In this submission, the methodologies used to determine age composition from haul seine catches alone and from gill net catches adjusted by haul seine catches were presented by the utilities' consultants. The two methods, as described in this submission, are given below:

(a) a proportion of fish which were caught by a 900-foot haul seine were aged and sexed. These fish were sorted into length groups (20 mm increments from 200-1120). The fish which were both sexed and aged ( $N_{S+A}$ ) were then used to estimate the number of fish from the total catch which would have fallen into each length group. Finally, the number of fish of each age and sex which were projected to be in each length group were summed across all length groups to determine the total number of fish in each age and sex group.

(b) gill net catches were adjusted for length-selectivity using data from a 900-foot haul seine. All samples below RM 38 were divided into 6 biweekly periods. The catches above RM 38 were very small and variable and were not used. For each time period, all fish were sorted into 200 mm length increments (starting with 200 mm). The proportion of males and females of each age was calculated for each length group. The length composition observed in the 900-foot haul seine catch was used to weight the catches. Finally, the number of fish of each age and sex were summed across all length groups in order to determine the proportion of each age and sex in the population sampled. These proportions were determined for each biweekly time period and an estimate of the mean and standard error of the proportions were obtained for each period. It was further indicated that if there were fewer than 4 fish of a particular age in a length increment, then these fish were not included in the analysis because small samples, according to the utilities, bias the data. Thus, part of the gill net catch was not used because it fell into groups of fewer than 4 fish.

The information in this utility submission contained four errors: (1) the reference to fish caught above RM 38 not being included in the adjustment of the gill net data with the haul seine data was incorrect; these fish were, in fact, included: (2) in the adjustment procedure,

"200 mm length increments" should have read "20 mm length increments," (3) the statement which indicated that, if there were fewer than four fish of a particular age in a length increment, then these fish were not included in the analysis, was incorrect, and (4) the first length increment did not start at 200 mm, but at 250 mm.

We incorrectly assumed that the utilities' September 26, 1977 submission contained correct information upon which to proceed in our analysis and in our preparation of cross-examination. In addition, we also incorrectly assumed that if any errors were contained in this document, they would have been corrected voluntarily by the utilities, given the length of time it was in EPA's possession prior to cross-examination (five months). However, it was not until five months later (March 9, 1978), when EPA began cross-examination on this topic, that the utilities provided us with corrections to this document; and then only the first two errors were corrected.

3. Utility submittal of April 12, 1978, in response to Questions 12 and 18 of a March 23, 1978 letter from Henry Gluckstern to Dr. Marcellus. The EPA questions were asked as follow-ups to information learned during cross-examination in the previous month. The utilities' responses provided a detailed description of the gill net adjustment procedure (response to Question 12) and a detailed description of the 1976 adult striped bass sampling program (response to Question 18). The response to Question 12 (Exhibit EPA-90) has a number of handwritten corrections written onto it. These corrections were made by Mr. McLaren during cross-examination on April 20, 1978 (Tr. 4005-09). The errors contained in the utilities' response to Question 12 were brought out during a technical session between EPA's technical consultants and the utilities' technical consultants on April 19, 1978 (McLaren, Tr. 3882-83). Through Exhibit EPA-90, the last two errors in the September 26, 1977 document were corrected. This Exhibit correctly indicated that (1) if there were fewer than four fish of all ages and sexes in a 20 mm length group, these fish were not included in the analysis, and (2) sorting into 20 mm length increments started at 250 mm, and not 200 mm, since only three fish were caught with lengths less than 250 mm.

### 3. RATIONALE WITH RESPECT TO THE UTILITIES' AGE COMPOSITION ANALYSIS

#### A. Importance of the "4 Fish Minimum Rule"

On pages 2-VIII-8 to 2-VIII-9 of Exhibit UT-3, the utilities state,

"Estimates of age composition based on combined gear (adjusted gill net) samples were preferred over estimates based on haul seine data. Gill nets were deployed in larger numbers and in more areas than the haul seine, which could be deployed effectively only at a few sample sites."

Since this statement contains the only rationale given by the utilities in their prefiled testimony for preferring the adjusted gill net data over the haul seine data alone, EPA incorrectly assumed that it was the only basis for preferring the adjusted data over the haul seine data, and proceeded accordingly until commencement of cross-examination on this topic (March 9, 1978). However, as will be apparent from the discussion in subsection (B) below, this was not the only reason which the utilities gave on cross-examination for preferring the adjusted gill net data over the haul seine data.

As described in the previous section, the haul seine length-frequency distribution was used in the gill net adjustment procedure. Since age, sex, and length are directly related (page 2-VIII-7 of Exhibit 3), we expected that the age composition resulting from the haul seine catch alone and the age composition resulting from the adjustment procedure would have been almost identical. This result was expected since (1) both data sets depend on the length-frequency distribution of the haul seine catch and (2) age, sex, and length are related. However, based on the haul seine age composition, the median age of reproduction is approximately 9 (McLaren Tr. 3936), whereas the median age of reproduction associated with the adjusted gill net data age composition is approximately 6 (Table 2-VIII-5 of Exhibit UT-3). This unexpected result was a consequence of the application of the "4 fish minimum rule," which had the effect of excluding older fish from the age composition analysis. EPA questioned the utilities regarding the validity of applying the "4 fish minimum rule" as it pertained to the determination of age composition, particularly female age composition. As described in the previous section, the "4 fish minimum rule" was the requirement that in each biweekly and regional determination of age composition, at least 4 aged and sexed fish be present in a 20 mm length increment. EPA, in preparing for cross-examination, had observed that application of this rule resulted in the rejection of many older fish from the age composition analysis. As it turned out, based on a May 10, 1978 letter from Dr. Marcellus to Henry Gluckstern, 135 out of the 144 fish (93.8 percent) of 690 mm or greater, which were aged and sexed, were never reflected in the age composition analysis. These fish correspond approximately to fish of age 7 and over (McLaren TR-5212). This result was due to the application of the "4 fish minimum rule." The rejection of

these older fish resulted in a substantial reduction in the calculated proportions of older females in the population. Table 2-VIII-4 of Exhibit UT-3 indicates that between 8 and 9 percent of the total number of females are seven and older. When no "4 fish minimum rule" is applied, the percentage increases to 23 percent (Exhibit EPA-218). The reduction in the proportion of older fish caused by the utilities' application of the rule resulted in a substantial reduction in calculated egg production by older fish, and a much lower median age of reproduction in the utilities' analysis. Table 2-VIII-5 of Exhibit UT-3 specifies the proportions of female striped bass by age when the utilities' "4 fish minimum rule" was applied. From this Table, a median age of reproduction of approximately 6.2 is obtained. From Table III-4 of the testimony of Fletcher and Deriso (Exhibit EPA-218), a median age of approximately 9 is obtained when no minimum fish rule is applied, which is almost identical to the median age resulting from only the haul seine catch data, as EPA expected originally.

On page 2-IV-4 of Exhibit UT-3, the utilities state that the lag time corresponds to the average age at which females spawn. Dr. Savidge and Mr. Croom testified that average age of reproduction was the preferred criterion to use when choosing lag times (Tr. 2519-20). Using a lag of 9 years between spawners and recruits, an alpha value of 1.64 is obtained when the Ricker model is fit to the utilities' catch per unit effort indices used to generate the alpha values on page 2-IV-28 of Exhibit UT-3. For a total conditional mortality rate of 0.2, the predicted equilibrium reduction in the striped bass population would be 45 percent. Thus, the validity or lack thereof of the "4 fish minimum rule" is extremely important in the context of the utilities' approach to power plant impact assessment.

B. Utility Rationale for the "4 Fish Minimum Rule" as it Pertains to the Determination of Age Composition

During the cross-examination of March 9, 1978, the utilities testified (McLaren Tr. 2841-42, 2861-62) that the "4 fish minimum rule" was based on the belief that 4 aged and sexed fish in a 20 mm length group was the minimum sample size needed to obtain an accurate sex ratio. When asked by EPA counsel if the application of the "4 fish minimum rule" caused a bias in the resulting age composition determination against older fish, the utilities testified (McLaren Tr. 2887),

...we are aware of a bias caused by the exclusion criteria ["4 fish minimum rule"], but we are also aware of other biases that would offset this bias, we believe."

The primary "offsetting bias" referred to by Mr. McLaren was the utilities' belief that the haul seine catch underestimated the numbers of 3, 4, and 5 year old striped bass in the population (McLaren Tr. 5273). This was based on the utilities' contention that (1) these younger age groups were best represented in the river during March and April (McLaren

Tr. 5177), but a large proportion of them left the population by the middle of the sampling season (McLaren Tr. 2888); and (2) the haul seine catch was taken primarily during a short time interval corresponding to the middle or just past the middle of the sampling season (McLaren Tr. 2889). The utilities argued that, as a consequence, the length-frequency distribution of the haul seine catch (hereafter referred to as the haul seine lfd), which reflects the proportion in each 20 mm length increment, underestimated those 20 mm length increments in which the 3, 4, and 5 year olds fell. The utilities testified that these included length increments up to 530 mm (McLaren Tr. 5177). Since the haul seine lfd was assumed to reflect the lfd of the Hudson River striped bass population in the utilities' computational scheme, the utilities contended that if all the older fish (defined here as fish of 690 mm or greater length) which were excluded by the "4 fish minimum rule" had not been excluded, the resulting age composition would have underestimated the number of 3, 4, and 5 year old striped bass, and consequently would have overestimated the older age groups.

In addition, the utilities argued that the age composition resulting from the application of no "four fish minimum rule," and the consequent inclusions of the excluded older fish, would have been inconsistent with natural mortality rates determined for the striped bass population in California (McLaren Tr. 5452-4).

## 4. VALIDITY OF THE UTILITIES' AGE COMPOSITION ANALYSIS

A. Analysis of the Utilities' "Offsetting Bias" Argument

In the previous section, we showed that the effect of the "4 fish minimum rule" was to reduce significantly the calculated proportion of fish 7 years old and older which would have resulted from the haul seine catch data alone or from the adjusted gill net data without application of a minimum fish rule. This, in turn, significantly reduced the calculated egg contribution of these older fish in the utilities' analysis. We also indicated that the utilities stated that this effect of the "4 fish minimum rule" was justified, since the haul seine catch and its resulting lfd underestimated the numbers of 3, 4, and 5 year olds in the striped bass population, and thereby, overestimated the proportions of the older fish in the population. However, under cross-examination, the utilities testified that no effort was made to quantify the claimed underrepresentation of these younger fish in the haul seine catch because the necessary information did not exist (McLaren Tr. 5179, 5182). On page 2-VIII-9 of Exhibit UT-3, the utilities state:

"Gill nets were strongly biased against catching these large fish, a fact which the selectivity correction procedure [adjustment of the gill net data] could not completely offset."

In summary, we understand the utilities to believe that the age composition resulting from the application of the "4 fish minimum rule" underestimates the proportion of older fish, and that the age composition, based on either the haul seine catch alone, or on the adjusted gill net data without a minimum fish rule, overestimates the proportions of these older fish. However, they maintain that the magnitude of the underestimate or overestimate cannot be quantified from the available information. Consequently, the utilities appear to claim that the median age of reproduction lies somewhere between 6.2 and 9.

If, as the utilities have argued, fish of ages 3, 4, and 5 were best represented in the months of March and April (McLaren Tr. 5177) and began to leave the population in significant numbers (relative to older fish) between April and May (McLaren Tr. 5177), then available gill net and haul seine lfd over time should reflect this phenomenon.

Exhibit AG-120 and AG-121 contain Tables of the lfd for the gill nets whose catch was used in the age composition analysis. These Tables were provided by the utilities. The tables of AG-120 were provided in a letter of June 2, 1978 from G. S. Peter Bergen to Paul Shemin. The tables of AG-121 were provided during cross-examination (Tr. 5264). The lfd are broken down by gear and time period in Exhibit AG-120, and by

gear, time period, and region in Exhibit AG-121. In each exhibit, the time periods correspond to:

1. 3/8 - 4/4
2. 4/5 - 5/2
3. 5/3 - 5/30
4. 5/31 - 6/30
5. After June

In Exhibit AG-121, only four gill nets are included. They correspond to the 4.0 inch, 4.5 inch, 5.0 inch, and 6.0 inch stretch mesh multifilament gill nets. These nets were the only gill nets fished continuously over the entire sampling period, and as a result, they caught approximately 80 percent of the fish caught by all gill nets. A review of the lfd for each of these four gear in both Exhibits AG-120 and AG-121 indicates that the 4.0 inch and 4.5 inch gill nets were able to catch relatively very few fish of lengths 531 mm or greater while the 6.0 inch gill net was able to catch relatively few fish of lengths 530 mm or less. Fish of lengths equal to or greater than 531 mm, which were caught by the haul seine and gill nets, corresponded to fish predominantly of ages greater than 5, whereas fish of lengths less than or equal to 530 mm which were caught by the haul seine and gill nets, corresponded predominantly to fish up to age 5 (McLaren Tr. 5177, Table 7.8-1 of Exhibit UT-4). Therefore, even if the abundance of the 3, 4, and 5 year fish decreased relative to the older fish over time, the lfd of the 4.0 inch, 4.5 inch, and 6.0 inch gill nets would not reflect this change in relative abundance.

However, based on the lfd of the 5.0 inch gill net, it appears that this gill net was able to catch fish of lengths equal to or greater than 531 mm, as well as fish of lengths less than or equal to 530 mm. Therefore, if the utilities' contention regarding the movement of the 3, 4, and 5 year olds is correct, then one should observe, for the 5.0 inch gill net, very similar fractions for the first two time periods (March and April) and a decline in this fraction in the third time period (May), corresponding to the time during which the 3, 4, and 5 year olds were supposed to be leaving the system relative to the larger and older fish.

Unfortunately, in May, the 5.0 inch gill net was deployed between RM 34-59, while in March and April, it was deployed between RM 26-42 (Exhibits AG-103 and AG-121). By concentrating the nets in the major striped bass spawning grounds in May (RM 47-60), the month when the peak spawning occurred in 1976 (Klauda Tr. 4894; Klauda Tr. 4900), the 5.0 inch gill net would have been expected to catch a greater proportion of larger and older fish, which consist principally of mature individuals. The immature 3, 4, and 5 year olds, which predominate these younger age classes, would not have been expected to make the spawning run. As a matter of fact, Dr. Klauda's and Mr. McLaren's testimony support this contention (Tr. 4901-02). Any difference between the lfd of the March/April periods and the May period was much more likely due to

the movement of the 5.0 inch gill net into the primary spawning grounds during the primary spawning period.

However, there is another way to test the utilities' contention regarding the movement of the 3, 4, and 5 year olds. The region sampled by the 5.0 inch gill net in March and April (RM 26-42) encompassed the area sampled by the haul seine (RM 33-39; Marcellus 1978). Therefore, if the utilities' claims are correct, (1) the proportion of fish caught of lengths less than or equal to 530 mm by the 5.0 inch gill net should have been relatively the same in March and April and (2) the haul seine lfd should have reflected a decreasing proportion of fish being caught up to 530 mm from the April period to the May period. A review of the lfd data contained in Exhibit AG-120 indicates almost no change in the proportion of fish of lengths up to 530 mm caught by the 5.0 inch gill net between March and April. During the March 8-April 4 period, this proportion was 0.63. During the April 5-May 2, this proportion increased to 0.68. This result is further substantiated by analyzing the lfd data contained in Exhibit AG-121. By combining the data on these two exhibits, one can compare proportions corresponding to RM 34-42 in a fashion analogous to the proportions given above for RM 26-42. The milepoints corresponding to RM 34-42 coincide fairly closely to the milepoints sampled by the haul seine (RM 33-39). The calculated proportions for the March 8-April 4 and April 5-May time periods corresponding to RM 34-42 are 0.62 and 0.68, respectively, and are almost identical to the calculated proportions corresponding to RM 26-42.

From Exhibit AG-120, the proportion of fish caught by the haul seine up to a length of 530 mm was 0.72 during the 4/ 5 - 5/2 period and 0.73 during the 5/2 - 5/30 period. These two periods correspond to the periods of time during which the haul seine caught all its fish. In addition, a more detailed breakdown of the haul seine lfd through time\* indicated no discernable trend in the proportions of fish caught in the size range dominated by the 3, 4, and 5 year olds (up to 530 mm). These results are set forth below:

Time Period	Total number of fish caught in time period by the 900 foot haul seine	Ratio of total number of fish <530 mm caught by the 900 ft. haul seine to the total number of fish of all lengths caught by the 900 ft. haul seine
4/5 - 4/21	44	0.82
4/28 - 4/30	67	0.69
5/05 - 5/07	62	0.81
5/10 - 5/17	90	0.63
5/25 - 5/28	75	0.79

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\*The information required to develop the more detailed breakdown was supplied by Dr. Webster Van Winkle of the Oak Ridge National Laboratory from a magnetic tape transmitted to him by Dr. Kenneth Marcellus on October 7, 1977.

Therefore, based on the lfd of the 5.0 inch gill net, there appeared to be no net movement of the 3, 4, and 5 year olds relative to the older age groups from March 8 to May 2 in the stretch of river in which the haul seine was deployed. Based on the fish caught by the 900 foot haul seine, there appeared to be no discernible decrease in the proportion of fish caught in the size range associated with the 3, 4, and 5 year old striped bass from April 5 to May 28. In addition, the 5.0 inch gill net catch indicated that the proportion of 3, 4, and 5 year olds was the same in March as in April between RM 26-42. Therefore, we conclude that the proportion of 3, 4, and 5 year olds caught by the haul seine would not have been expected to be any greater if it had caught fish between March 8 and April 4 and/or if it had caught more fish in April than it actually did catch. Therefore, based on the available haul seine lfd information, there appears to be no valid support for the utilities' contention that the 3, 4, and 5 year olds left in any greater proportion than the older age groups in May, and based on the available haul seine and gill net lfd, there appears to be no valid support for the utilities' contention that the haul seine lfd underestimated the proportion 3, 4, and 5 year olds. However, other available information (discussed below) does indicate that the 3 year olds appeared to be underestimated by the gill nets.

B. Consistency Between the Utilities' Calculated Age Composition and Information on Natural Mortality and Year-Class Strength

In the previous section, we indicated that the utilities believed that the age composition based on the haul seine lfd without application of the "4 fish minimum rule" was unrealistic because it resulted in a calculated total mortality rate of only 20 percent for female striped bass. It was felt that such a mortality rate "...fell quite outside the normal range" (McLaren Tr. 5453). We agree. However, the same result can be obtained from the age composition resulting from application of the "4 fish minimum rule." These "unrealistically" low calculated mortality rates are due to the inclusion of 3 year old fish in the mortality determination. If they were not included, a more "realistic" (in the utilities' view) total mortality rate of approximately 30 percent would be obtained from both sets of age compositions.

The 3 year olds caught in 1976 come from the 1973 year-class. Juvenile abundance data indicates that this year-class was large, significantly larger than the 1972 year-class, from which the 4 year old fish caught in 1976 come (Table 2-VIII-9 and page 2-VIII-20 of Exhibit UT-3; page 7.170 of Exhibit UT-4). Therefore, the age composition derived by the utilities should reflect this fact. It does not. The proportion of 3 year olds of both sexes is less than the proportion of 4 year olds of both sexes (Table 2-VIII-4 of Exhibit UT-3). As a matter of fact, the proportion of 3 year olds of both sexes is also less than the proportion of 5 year olds of both sexes. The age composition resulting from the adjustment procedure without application of a minimum fish rule also appears to underestimate the proportion of three year olds, although not as much for males as the utilities' calculated age composition does. Without application of the minimum fish rule, the proportion of 3 year

old males is the highest proportion by age for this sex. However, Figure 2-VIII-2 of Exhibit 3 (i.e., haul seine age composition) indicates that the 3 year olds caught by the haul seine accounted for 40 percent of the catch, with the proportion of males and the proportion of females of age 3 each being at least approximately twice as great as the proportion of males or females of any other age. This result is consistent with the information concerning the strength of the 1973 year-class. The haul seine age composition also results in "realistic" calculated total mortality rates (approximately 47 percent for males and 30 percent for females) even with the inclusion of the 3 year old age class. It, therefore, appears that the gill net catches, which were used in the assignment of ages and sexes within the 20 mm length increments of the haul seine catch in the adjustment procedure, underestimated the proportion of 3 year olds in the population. This underestimation was probably due to the movement of the gill nets up into the primary spawning grounds in May (RM 47-60), where one would not expect to find the almost totally immature 3 year old age group. This underestimation most probably led to an underestimate of the proportion of 3 year olds during May in the biweekly age compositions for the region above RM 38. The haul seines, on the other hand, were deployed below the primary spawning grounds (RM 33-39) where one would have expected to find a greater proportion of 3 year olds.

The effect of the underestimation of 3 year olds in the adjusted gill net data age composition on egg production by age is small. A very small percentage of 3 year old females are mature (Table 2-VIII-1 of Exhibit UT-3), and their fecundity is relatively low compared to the older age groups (Table 2-VIII-5 of Exhibit UT-3). As a result they contribute very little to the egg production of the population. As such, the fact that their numbers were underestimated in 1976 by the gill nets has little effect on the calculated distribution of egg production by age, or on the median age of reproduction, derived from the age composition of the adjusted gill net data with or without the application of the "4 fish minimum rule."

A knowledge of year-class size can also be used to show that the "4 fish minimum rule," by excluding 135 out of the 144 fish of lengths 690 mm or greater which were aged and sexed, significantly underestimated the number of 7 years olds. The 7 year olds caught in 1976 are survivors of the 1969 year-class which appeared to be a large year class, the second largest year class in the period for which juvenile abundance estimates are available (Table 2-VIII-9 of Exhibit UT-3 and page 7.188 of Exhibit UT-4). Juvenile abundance data indicate that it was a larger year-class than that of 1970, from which the 6 year olds caught in 1976 came (Table 2-VIII-9 of Exhibit UT-3), although no significant difference between the sizes of the two year-classes were found (page 2-VIII-20 of Exhibit UT-3). However, the utilities' calculated age composition (Table 2-VIII-4 of Exhibit UT-3) showed that the proportion of 7 year old males was 0.015, compared to 0.079 for 6 year old males. For 6 and 7 year old females, the numbers were 0.077 and 0.022, respectively. Even given equal year-class strengths in 1969 and 1970, this indicates a total yearly survival from age 6 to age 7 of about 19 percent for males and 29 percent for females. Given the utilities' estimates of fishing mortality

of 12-18 percent per year (McLaren Tr. 5453), a natural mortality of between 64-78 percent must have occurred between ages 6 and 7 to be consistent with the utilities' calculated proportions by sex for the 6 and 7 year olds. If the 1969 year-class was larger than the 1970 year-class, at some information indicates, the indicated range of natural mortality rate would be even higher (i.e., the relative proportions by age are the result of mortality and relative year-class size). Such a range of natural mortality is unrealistically high, particularly for age 6 females. The age composition derived from the adjusted gill net data without the application of a minimum fish rule indicated a more realistic range of natural mortality of 46-50 percent for males and 16-22 percent for females, between years 6 and 7, given equal year-class strength in 1969 and 1970. If the 1969 year-class was greater than the 1970 year-class, then the indicated natural mortality rates would be higher (possible unrealistically high for males depending upon the relative sizes of the 1969 and 1970 year-classes).

It is interesting to note that the haul seine age composition (Figure 2-VIII-2 of Exhibit UT-3) indicates that the proportion of 7 year olds (males and females combined) was higher than the proportion of 6 year olds (approximately 0.08 to 0.06). This is consistent with some of the information concerning the sizes of the 1969 and 1970 year-class.

In conclusion, based on (1) length-frequency distribution data available over time for both the 5.0 inch gill net used in the 1976 adult striped bass sampling program and the 900 foot haul seine; and (2) information available on year-class size in 1969, 1970, 1972 and 1973, the age composition derived from the combined gill net and haul seine data adjusted to the length-frequency distribution of the haul seine catch without application of any minimum sample size of aged and sexed fish in a 20 mm length increment is more valid than the age composition derived with the same data, but with application of the "4 fish minimum rule." However, it does not appear to be as valid as the age composition resulting from the haul seine catch alone.

#### C. Validity of the "4 Fish Minimum Rule" With Respect to the Determination of Age-Specific Sex Ratios

In Section III-B, we indicated that the utilities based the "4 fish minimum rule" on their belief that 4 aged and sexed fish in a 20 mm length increment was the minimum sample size needed to obtain accurate age-specific sex ratios when working under the assumption of a 1:1 sex ratio. A review of EPA-90 (utility methodology used to determine age composition of the Hudson River striped bass population) indicates that age-specific sex ratios were not calculated within 20 mm length increments, but were calculated after the number of fish of each age and sex was summed across all length increments (McLaren Tr. 5354; McLaren Tr. 5356)

If age-specific sex ratios were not calculated within length increments, then why was the "4 fish minimum rule" applied to length increments? When asked this question during cross-examination,

Mr. McLaren testified that the "4 fish minimum rule" was applied within the 20 mm length increments because the aged and sexed fish from the combined gill net and haul seine catch in each 20 mm length increment were used to categorize the ages and sexes of fish in each corresponding haul seine length increment, and were then weighted by the proportion of each length increment in the haul seine lfd in the utilities' computational scheme (McLaren Tr. 5358). Therefore, Mr. McLaren testified, a minimum fish rule within length increments was needed to accurately categorize, by sex and age, each 20 mm length increment of the haul seine catch (McLaren Tr. 5360). But then, there is no basis for the number 4 in the "4 fish minimum rule." The "4 fish minimum rule" would only be valid if age-specific sex ratios were calculated within length increments. When asked why the utilities did not abandon the "4 fish minimum rule," Mr. McLaren testified that its abandonment would have left the utilities with an unrealistic age composition, in that it would have overestimated the number of older fish in the population, and would have been consistent with unrealistically low natural mortality rates (McLaren Tr. 5367). However, Mr. McLaren did not know the extent of the alleged overestimation of older fish (McLaren Tr. 5179, 5182) and we have demonstrated that the age composition which results from abandonment of the "4 fish minimum rule" is more "realistic" in Mr. McLaren's sense that the utilities' calculated age composition in that it is more consistent with available information on year-class strength and natural mortality.

We, therefore, conclude that there is no valid basis for the "4 fish minimum rule" as it was applied by the utilities. Its effect, however, is to give the utilities a calculated female age composition which results in an age-specific egg production distribution and median age of reproduction more consistent with their preconceived notion concerning age composition and egg production. Before the utilities had available the data from their 1976 adult striped bass sampling program, they hypothesized that 5 and 6 year old fish dominated the spawning stock, i.e., that they were the dominant egg producers (Page 10.43 of Exhibit UT-4, Page 2-IV-4 of Exhibit UT-3, and McFadden Tr. 2387). A comparison of Table III-4 of the testimony of Fletcher and Deriso (Exhibit EPA-218) and Table 2-VIII-5 of Exhibit UT-3 indicates that application of the "4 fish minimum rule" in the adjustment procedure increases the calculated egg contribution of the 5 and 6 year olds at the expense of the 10 and 12 year olds. This result allows one better to justify, using the utilities' logic, the inclusion of age 5 when selecting various lag times. Inclusion of age 5 in a lag time analysis results in the generation of higher alpha values than would be generated without its inclusion (Page 2-IV-28 of Exhibit UT-3 and Table 1 of Exhibit UT-58). Based on the age composition resulting from no minimum fish rule (Table III-4 of Exhibit EPA-218), if one were to choose a lag time based on various of the utilities' egg contribution criteria (see McFadden Tr. 2390) one would, for a single age, choose age 7; for two consecutive ages, choose ages 6 and 7, and, for consecutive ages, choose ages 10, 11, and 12. In this case, age 5 is but a minor contributor (6.10 percent), and would not appear in any of the lag times.

## 5. CONCLUSIONS

1. Based on the length frequency distribution data for March and April from the 5.0 inch gill net, it appears that there is no evidence for greater movement of 3, 4, and 5 year old striped bass out of the region of the Hudson River between either milepoints 26 and 42 or milepoints 34 and 42 than there is for the older age groups.
2. Based on the length-frequency distribution data in April and May from the 900 foot haul seine, there appears to be no discernible decline in the proportions of 3, 4, and 5 year olds being caught between milepoints 33 and 39 (the region in which the haul seine was deployed).
3. Based on (1) and (2) above, it appears that, if the haul seine had caught more fish in March and more fish in April than it actually did catch, and this catch were included in the determination of the length-frequency distribution, this new length-frequency distribution would be very similar to the actual computed haul seine length-frequency distribution.
4. Based on (1), (2), and (3) above, the utilities' contention that the haul seine catch underestimated 3, 4, and 5 year-old striped bass cannot be supported.
5. Based on information concerning year-class size in 1972 and 1973, it appears that the age composition resulting from the adjustment procedure, either with or without application of the "4 fish minimum rule," underestimates the number of 3 year olds in the population. However, this underestimation will have very little effect on estimates of the relative egg contribution of the older classes (4 and above) and the median age of reproduction, because the 3 year old females contribute relatively very few eggs because of their low percent maturity and relatively low fecundity. However, based on the above information concerning year-class size, it appears that the 900 foot haul seine did not noticeably underestimate the number of three year olds in the population.
6. Based on information concerning year-class size in 1969 and 1970, it appears that the utilities' derived age composition (Table 2-VIII-4 of Exhibit UT-3) indicates an unrealistically small proportion of 7 year old fish relative to 6 year old fish. This was probably the result of the exclusion of a large number of 7 year old fish relative to 6 year old fish through application of the "4 fish minimum rule." The age composition resulting from application of no minimum fish rule, or the age composition resulting from the haul seine catch alone, is more consistent with respect to the information concerning year-class strength.
7. Based on (4) and (6) above, it appears that the age composition derived from (1) the adjusted gill net data without application of a minimum fish rule of sexed and aged fish in a 20 mm length increment, or

(2) the 900 foot haul seine catch alone, is more valid than the age composition derived from the adjusted gill net data with application of the "4 fish minimum rule", and is, therefore, more valid for the stated purposes of the utilities (determining lag times to use in stock-recruitment curve fits). Using the median age of reproduction as the criterion for selecting an appropriate lag time, the above conclusion would result in the choice of a lag time of 9 years, and a resulting alpha value of 1.64. With a total conditional mortality rate of 0.2, for example, the utilities' equilibrium reduction equation would predict a 45 percent reduction in the striped bass population.

8. There appears to be no valid basis for the utilities' selection of the "4 fish minimum rule" as they apply it. This conclusion is based on the following:

(a) the "4 fish minimum rule" was applied to all aged and sexed fish in 20 mm length increments;

(b) its purpose was to allow the utilities to determine accurate age-specific sex ratios;

(c) sex ratios were not calculated within length increments; even if they were, the "4 fish minimum rule", as applied to all aged and sexed fish in a 20 mm length increment, rather than to specific ages in a 20 mm length increment, would still be applied invalidly;

(d) the actual application of the "4 fish minimum rule" appears to have been to attempt to ensure a sufficient sample size to accurately categorize the ages and sexes of fish in the 20 mm length increments of the haul seine catch; as such, no rational basis has been provided by the utilities for the selection of the number 4 in the "4 fish minimum rule;"

(e) based on (4) above, the effect that the "4 fish minimum rule" had, namely, the exclusion of 93.8 percent of the aged and sexed fish of lengths of 690 mm and greater, was not "offset" by an underestimate of ages 3, 4, and 5 in the haul seine catch.

9. The effect of the "4 fish minimum rule" appears to be the generation of an age composition and egg production distribution by age which allows one to select a lag time which includes age 5; this selection results in the generation of higher alpha values than would be generated without its inclusion, and consequently smaller predictions of power plant impact using the utilities' impact assessment methodology.

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CHAPTER VII

A CRITICAL EVALUATION OF THE LAWLER, MATUSKY AND SKELLY  
TWO-DIMENSIONAL, REAL-TIME, LIFE-CYCLE MODEL OF THE  
HUDSON RIVER STRIPED BASS POPULATION

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## 1. SUMMARY AND CONCLUSIONS

The total entrainment conditional mortality rate predicted by the 2-dimensional, real-time, life-cycle model (RTLTC) for the Hudson River striped bass population for "1974 conditions" at Bowline Point, Roseton and Indian Point Units 2 and 3 is underestimated by approximately 24%. The causes of this underestimate are:

- (1) The generation of longitudinal spatial distributions of  $ys_1$  and  $pys_1$  by the RTLTC results in an underestimate of power plant impact of approximately 10% for  $ys_1$  and 25-30% for  $pys_1$  (Section 9).
- (2) Juvenile I entrainment at Bowline Point is underestimated (Section 8).

It is difficult to quantify the underestimate of juvenile I entrainment at Bowline Point. If an entrainment rate equal to that of 1975 is assumed for 1974, then consideration of the above two effects results in an  $M_E$  value of 0.060 for 1974 conditions, which is 24% greater than the  $M_E$  value of 0.0492 predicted by the RTLTC.

The total entrainment conditional mortality rate predicted by the RTLTC for "1975 conditions" at Bowline Point, Roseton and Indian Point Units 2 and 3 is underestimated by approximately 23%. The causes of this underestimate are:

- (1) The generation of longitudinal spatial distributions of  $ys_1$  and  $pys_1$  by the RTLTC results in an underestimate of power plant impact of approximately 25-30% for  $pys_1$  (Section 9).
- (2) Juvenile I entrainment at Bowline Point is underestimated (Section 8).

Again, it is difficult to quantify the underestimate of juvenile entrainment at Bowline Point in 1975. If the entrainment rate at Bowline Point utilized by the utilities in their 1975 RTLTC prediction of  $M_E$  is assumed to be one-half of the true value, then accounting for only the above two factors results in an  $M_E$  value of approximately 0.0967, which is 23% greater than the  $M_E$  value of 0.0783 predicted by the RTLTC.

The RTLTC does not accurately predict the longitudinal spatial distribution of  $ys_1$  or  $pys_1$  in 1974 or of  $pys_1$  in 1975 for purposes of accurately predicting power plant impact. Consequently, we cannot have confidence in the ability of the RTLTC to accurately predict the longitudinal spatial distributions of  $ys_1$  and  $pys_1$  and the associated  $M_E$  values in any other year (Section 9). The RTLTC tends to move the  $ys_1$  and  $pys_1$  too far downstream, such that an unrealistically high percentage of these two life stages is predicted to be in Regions 1 and 2, which are below

the regions containing the power plants. This tendency results in an underestimate of total power plant impact for ysl and pysl (Section 9). The RTLC predicts patterns of movement for ysl and pysl in the TI regions containing the power plants that, for the most part, do not agree with the patterns of movement indicated by the TI field data (Section 9).

The entrainment and impingement conditional mortality rates predicted by the RTCL are to a great extent consistent with environmental and biological conditions present in the Hudson River in 1974 or 1975 only. Therefore, application of these conditional mortality rates to years other than 1974 or 1975 is not valid, unless these years can be shown to have had almost identical environmental and biological conditions to those of 1974 or 1975 (Section 3).

Given the validity of the utilities' arguments concerning density-dependent growth, the prediction of  $M_T$  by the RTLC is underestimated. The underestimate, in this case, is the result of a density-dependent-caused decrease in the life stage durations for ysl and pysl input to the RTLC (Section 5). This decrease is a result of an increase in larval growth rate due to power plant operation (i.e., the compensatory response of density-dependent growth due to reduction in larval density), which the utilities claim occurred in both 1974 and 1975.

Given the validity of the methodology employed by the utilities to predict long-term, power plant impacts on the striped bass population, and given the methodology they employ to quantify the "amount of compensation" in the striped bass population, the operation of Lovett Units 4 and 5 and Danskammer Point Unit 4 should be reflected in the total conditional mortality rate predicted by the RTLC (Section 6). Because it is not, the long-term reduction in the equilibrium striped bass population is underestimated.

The results of the stochastic modelling approach are invalid because (Section 4):

- (1) They are based on an invalid tool for predicting long-term power plant impact.
- (2) They are based on a value of alpha which is an artifact of the methodology used to derive it (fitting the Ricker Model to striped bass catch per effort indices).
- (3) They are based on an invalid assumption that the one-dimensional transport model and RTLC give very similar predictions of conditional entrainment mortality rates for larvae under varying environmental and biological conditions.

The RTLC has certain properties which are inconsistent with biological principles or with testimony presented by other utilities' consultants, including those consultants who developed the RTLC (Section 7). These properties are:

- (1) independence between egg production and early life stage survival;
- (2) incorporation of a compensatory function (Beverton-Holt mortality rate function) (i) which is inconsistent with the Ricker Model, but (ii) which is consistent with a stock-recruitment model rejected by a utilities' consultant who served as a member of the panel of expert witnesses on the RTALC.
- (3) application of compensation after year-class strength has been set;
- (4) variation of freshwater flow in the stochastic modelling approach, while keeping stage durations and early life stage survivals constant, when the utilities believe that these three processes are related in the real world.

Based on the above, it is our opinion that the RTALC is not a reliable tool for making sound fisheries management decisions.

## 2. INTRODUCTION AND PURPOSE

On page 3-I-1 of Exhibit UT-3 (hereafter denoted simply UT-3), it is stated that the Striped Bass Real-time Life Cycle Model (hereafter denoted RTLCL) "... provides quantitative short and long-range predictions ... of ... impact on the striped bass population." The impacts referred to are power plant entrainment and impingement. On page 3-II-1 of UT-3, it is stated that the RTLCL is used to predict the reduction in the equilibrium striped bass spawning stock. One purpose of our testimony is to critically evaluate the ability of the RTLCL to accurately provide short-range predictions of power plant entrainment and impingement impacts under various environmental and biological conditions. (Short-range predictions are defined as entrainment, impingement, and total conditional mortality rates.)

Long-term predictions of impact will not be addressed, owing to the fact that the RTLCL is not utilized to independently predict such impact. The RTLCL predicts a total conditional mortality rate,  $M_T$  (Englert, Tr. 9441); the equilibrium reduction equation, i.e., the ERE (Equation 3-V-2 on page 3-V-7 of UT-3), then predicts the long-range reduction in the equilibrium striped bass population associated with  $M_T$  (pages 3-VIII-1 and 2 of UT-3). Finally, the RTLCL, through a specific calibration procedure, is made to generate the long-range reduction predicted by the ERE (p. 3-V-8 of UT-3). Therefore, the ERE will be critically evaluated in other EPA testimony with respect to its ability to accurately predict long-range reductions in the striped bass population.

A second purpose of our testimony is to critically evaluate certain features of the RTLCL with respect to their being consistent with known biological principles and other testimony submitted by the utilities.

A third purpose of our testimony is to critically evaluate certain analyses presented in Part 3 of UT-3 which purport to support values assigned to specific RTLCL input parameters and/or which purport to support RTLCL results.

## 3. EMPIRICAL NATURE OF THE RTLC

The Empirical Transport Model (ETM) and the Empirical Impingement Model (EIM) have been utilized by EPA to determine entrainment and impingement conditional mortality rates ( $M_E$  and  $M_I$ , respectively) for specific Hudson River fish populations, including striped bass. The word "empirical" is included in the title of these two models because the conditional mortality rates which have been estimated by the above models are for the years 1974 and 1975, in that various input parameters have been evaluated based on data collected in 1974 or 1975 (e.g., impingement rates and w-ratios). Because (1) much of the input data to these two models reflects the environmental and biological conditions existing in each of these two years (e.g., Hudson River freshwater and tidal flows and temporal and spatial distribution of young-of-the-year (yoy) life stages), and (2) biological and environmental conditions (and the data reflecting these conditions) vary from year to year, EPA makes no claims regarding the validity of the estimates of conditional mortality rates for years other than 1974 or 1975. In fact, EPA would object to anyone claiming that these rates are valid for any other year.

The RTLC has been used to estimate power plant entrainment and impingement conditional mortality rates for striped bass. Such estimates have been presented in Table 3-VIII-1 of UT-3, as revised. It will be noted that two sets of estimates of  $M_E$  and  $M_I$  have been given, one for 1974 and one for 1975. As was the case with the ETM and EIM, these estimates were based on data collected under environmental and biological conditions existing in the Hudson River in 1974 and 1975, respectively. Therefore, as is the case with the ETM and EIM, the RTLC is also an empirical model, in that most of its input parameters have been evaluated from data collected in 1974 or 1975. Thus, its estimates of  $M_E$  and  $M_I$  are valid only for these two years.

To show that the RTLC is, in fact, an empirical model, one need only (a) isolate those input parameters which principally determine  $M_E$  and  $M_I$ , (b) show that the values assigned to those parameters are, for the most part, based on data collected in 1974 or 1975, and (c) show that such data reflect the biological and environmental conditions existing in 1974 or 1975, conditions which can be expected to vary from year to year. Those input parameters to the RTLC which principally determine  $M_E$  and  $M_I$  are listed in Table 1. We will first examine what data each of the input parameters are based on. We will then examine these data to see if they reflect the biological and environmental conditions existing in 1974 or 1975 and if such data can be expected to vary from year to year.

A. Eggs, YSL, PYSL

Starting with the input parameters which determine  $M_E$  for eggs, yolk-sac larvae (ysl), and post yolk-sac larvae (pysl), Items A.1 through A.5.a of Table 1 determine the temporal and spatial distributions of these

Table 1. RTLc input parameters which principally determine the entrainment and impingement conditional mortality rates

- 
- A.  $M_E$  (eggs, yolk-sac larvae, post yolk-sac larvae)
1. temporal and spatial egg distribution
  2. tidal flow simulation of RTLc\*
  3. larval migration
  4. stage durations
  5. composite f-factor
    - a. w-ratios\*
    - b.  $f_c$ \*
    - c.  $f_q$ \*
    - d. recirculation ratio\*
  6. power plant intake flow rates
- B.  $M_E$  (juvenile I)
1. numbers killed by entrainment
  2. natural survival through the pysl stage
  3. natural survival through the juvenile I stage
- C.  $M_I$
1. numbers killed by impingement
  2. natural survival through the juvenile I stage
  3. natural survival through the juvenile II and juvenile III stages
- 

\*Tidal flow and Items 5.a - 5.d are not part of the input data file, and therefore, they cannot be strictly classified as RTLc input parameters. However, tidal flow is based on data input to the RTLc, and Items 5.a - 5.d are the components of a RTLc input parameter.

three life stages in the longitudinal and vertical dimensions, the length of time individual organisms are susceptible to entrainment, and the spatial distribution in the lateral dimension in the power plant segments. In other words, Items A.1 through A.5.a determine the vulnerability of eggs, ysl and pysl to power plant entrainment. The values assigned to Items A.1, A.3 and A.5.a are calculated directly from sampling data collected by Texas Instruments (TI), Lawler, Matusky and Skelly Engineers (LMS), or New York University (NYU) in 1974 and 1975 [see Sections 3-IV-C.1, 3-IV-C.4 and 3-IV-D.2(c) of UT-3].

Item A.2, tidal flow, principally determines the movement of eggs, ysl and pysl in the longitudinal direction. The equations utilized in the RTLC to simulate the tidal flow of the Hudson River are parameterized to simulate the actual 1974 and 1975 tidal flows, and in turn, the actual 1974 and 1975 longitudinal spatial distributions of the ysl and pysl stages. One of the input parameters to the RTLC tidal flow equations is freshwater flow. Since 1974 and 1975 freshwater flows are input data to the RTLC, the tidal flows calculated are truly valid for only 1974 or 1975.

The stage durations input to the RTLC for eggs, ysl and pysl (Item A.4) of Table 1 are determined from sampling data collected in 1974 or 1975 by TI. The data used were the river standing crop estimates of each life stage over time. The stage durations were determined by LMS calibrating of the RTLC to these sampling data. Very briefly stated, through the calibration procedure, stage durations for eggs, ysl and pysl were chosen by LMS which resulted in the RTLC predicting peak standing crop estimates for each life stage that coincided, in the temporal dimension, with the peak standing crop estimates based on TI's riverwide sampling data. Therefore, the stage durations input to the RTLC are based on 1974 and 1975 river ichthyoplankton standing crop estimates derived by TI.

Items A.5.b through A.6 of Table 1 constitute those input parameters which reflect the operation of the power plants (i.e., amount of river water withdrawn and fraction of entrained organisms which are killed). The values assigned to Items 5.b, 5.c and 5.d were based on special short-term studies by the utilities; the values for Item 6 were based on the average power plant flow rates projected by the utilities for Roseton, Bowline Point and Indian Point Units 2 and 3 for the years 1976 - 2013.

## B. Juvenile I's

$M_E$  for juvenile I's depends on three input parameters. Item B.1 of Table 1 (i.e., numbers killed by entrainment) is based on the numbers entrained per unit volume of intake water in either 1974 or 1975,  $f_c$  for this life stage, and the average projected power plant flow rates for the period 1976 - 2013. Previous comments with respect to these latter two parameters (reference above discussion on  $M_E$  for eggs, ysl, and pysl) hold.

The values assigned to Items B.2 and B.3 of Table 1 determine the juvenile I standing crop which is vulnerable to entrainment. These values were determined from the LMS calibration procedure. Through the calibration procedure, values for natural survival through the pysl stage for 1974 and for 1975 were chosen which resulted in the RTLC generating pysl standing crop estimates over time comparable to the TI riverwide estimates in each of the two years. Juvenile I natural survival was obtained through the calibration procedure by choosing a value for natural survival in both 1974 and 1975 which resulted in the RTLC generating a peak juvenile II standing crop in the fall comparable to the peak riverwide standing crop estimates for juveniles in the fall in each of these years. Consequently, Items B.2 and B.3 are empirical input parameters in that they are based on data collected in 1974 and 1975.

### C. Juveniles II-III's

$M_I$  depends on three input parameters. Item C.1 of Table 1 is based on the numbers impinged per unit volume of power plant intake water in 1974 or 1975 and on average projected power plant flows for the period 1976 - 2013. Again, previous comments with respect to the projected power plant flows hold. Items C.2 and C.3 of Table 1 determine the juvenile II and juvenile III standing crops which are vulnerable to impingement. These input parameters were estimated through the LMS calibration procedure. The estimation of natural survival rate for juvenile I's has already been discussed. Natural survival rates for juvenile II's and juvenile III's were chosen by LMS which resulted in the RTLC generating a peak standing crop of fall juveniles comparable to the peak standing crop of fall juveniles estimated by TI in 1974 and 1975 and a standing crop of 1-year olds of 1.2 million. The 1.2 million figure was based on 1975 survival estimates of juveniles from fall to spring, and it represents an estimate of the 1976 standing crop of 1-year olds. LMS applied this standing crop estimate of 1-year olds to the 1974 year class, since no reliable survival estimates for the 1974 juvenile II and juvenile III stages were available. Based on the above, it is apparent that  $M_I$  for 1974 and 1975 depends to a very great extent on data collected in both 1974 and 1975.

### Conclusions

It can be seen, based upon the above discussion, that there are numerous input parameters upon which the entrainment and impingement conditional mortality rates depend. The value of only one of the input parameters in Table 1, average projected power plant flows for the period 1976 - 2013, is not either entirely or partially dependent on data specific to 1974 or 1975. An indirect method of determining if the data upon which  $M_E$  and  $M_I$  depend varies from year to year, and if it does, to what degree, is to compare the RTLC predictions of  $M_E$  and  $M_I$  for the years 1974 and 1975. The magnitude of the changes in  $M_E$  and  $M_I$  in these two

years can be used as an index of the magnitude of the changes in the input data. The large variation between the 1974 - specific data and 1975 - specific data is apparent when comparisons of  $M_E$  and  $M_I$  for each of these years are made (Table 2).

Table 2. Comparison of RTLC predicted  $M_E$  and  $M_I$  values under 1974 and 1975 environmental and biological conditions

Conditional mortality rate	Year		Percent change <sup>a</sup>
	1974	1975	
$M_E$	0.0492	0.0783	-59%
$M_I$	0.0686	0.0361	+47%
$M_T$ <sup>b</sup>	0.1144	0.1116	+2.4%

$$^a \text{Percent change} = \frac{1974 \text{ value} - 1975 \text{ value}}{1974 \text{ value}} \times 100$$

$$^b M_T = 1 - (1 - M_E)(1 - M_I)$$

The percent change in  $M_E$  between 1974 and 1975 was -59%, while the percent change in  $M_I$  between 1974 and 1975 was +47%. If the 1974  $M_E$  or  $M_I$  values were assumed for 1975, that assumption would have been shown to be invalid when the 1975 estimates of  $M_E$  and  $M_I$  were made. The point is that one cannot assume that 1974 or 1975  $M_E$  or  $M_I$  values are valid for any other year.

One might note that the total conditional mortality rates in 1974 and 1975 were similar (0.1144 in 1974 versus 0.1116 in 1975). This similarity was obviously due to the large change of similar magnitude, but of opposite sign, in  $M_E$  and  $M_I$ . However, one cannot rely on such good fortune for other years. It is quite conceivable, for example, that values similar to the 1974  $M_E$  and 1975  $M_I$  values could occur in a single year or that values similar to the 1974  $M_I$  and 1975  $M_E$  values could occur in a single year. Based on these two combinations of  $M_E$  and  $M_I$  values,  $M_T$  could range from 0.0835 - 0.1415. The point is that inserting either the 1974 or 1975  $M_T$  value into the ERE will give accurate long-range impact estimates only by chance alone, even given the assumption that the ERE is a valid tool for impact assessment.

A final conclusion based on the above analysis is that if one wanted to determine the relative impact of entrainment and impingement, and from this determination institute specific mitigation measures, one would draw opposing conclusions in 1974 versus 1975. Based on 1974 "conditions," we would conclude that impingement has a greater impact than entrainment, whereas, based on 1975 conditions, we would draw the conclusion that entrainment has a greater impact than impingement. Therefore, it is apparent that with projections from only two years the relative impact of entrainment and impingement is not known.

#### 4. STOCHASTIC MODELING APPROACH PRESENTED IN SECTION 3-VI OF UT-3

The "Stochastic Modeling Approach" presented in Section 3-VI of UT-3 suffers from two main deficiencies from our perspective: (1) the "type" of results presented and (2) the use of the one-dimensional transport model to generate the results.

##### A. Type of Results Presented

Figure 3-VIII-1, opposite page 3-VIII-6 of UT-3, depicts the temporal variation of the Hudson River adult striped bass population for the period 1974 - 2016 based on the stochastic modelling approach. LMS utilized its one-dimensional transport model (T-Model) with compensation operating (calibration of the T-Model to the ERE, with an alpha value of 4.0) to generate these results. Once "equilibrium" was attained, the population fluctuated between approximately 2.19 million and 2.34 million. Given a non-impacted population of 2.43 million, the percent reduction fluctuated between 3.6% and 9.7% (page 3-VIII-5 of UT-3).

It is our opinion that the presentation of the results in the form of "variation in the adult striped bass population with the operation of compensation" is inappropriate. The validity of the results depends in part on the validity of the calibration of the compensation function of the T-Model to the ERE with an alpha value of 4.0 (or with any other alpha value). If the Ricker model (and the ERE derived from it) is not a valid tool for determining the amount of compensation operating in the striped bass population and the degree of power plant impact, then the results presented in Section 3-VI of UT-3 are also invalid. Based on testimony presented elsewhere (Exhibits EPA-213, 214, and 215), these results are, indeed, invalid. We contend that results which depicted fluctuations in larval entrainment conditional mortality rates, as predicted by the RTLC, should have been presented. This contention is based on the facts that (1) the variables chosen for stochastic variation principally affect larval entrainment, and (2) that the T-model and RTLC are not interchangeable. These two points are discussed below.

##### B. Use of the T-Model and Choice of Larval Conditional Mortality Rate

On page 3-VI-13, it is stated that (1) the RTLC and the T-Model were used in tandem in order to avoid unnecessary computer costs by the utilities; (2) that the parameter values of the T-Model were adjusted so that predictions of impact from the model agreed with those of the RTLC after 40 years; and (3) that the stochastic sequence of (a) freshwater flows, (b) spatial and temporal egg distributions, and (c) the w-ratios of eggs and larvae were input to the T-Model to provide the results depicted in Figure 3-VIII-1. In response to an EPA Region II question pertaining to the above adjustment procedure (August 18, 1978 letter from Dr. Kenneth Marcellus to Henry Gluckstern), it was indicated that no adjustment was done and that

given input parameter values based on 1974 data, the RTLC and T-Model predicted very similar total conditional mortality rates ( $M_T$ ) of 0.1144 and 0.1123, respectively. In addition, during cross-examination of the utilities' direct case, it was indicated that, given input parameter values based on the 1975 data base, the RTLC and T-Model predicted  $M_T$  values of 0.1116 and 0.1102, respectively (Englert Tr. 10,042). It was then concluded that the closeness of the  $M_T$  values predicted by the two models provided justification for using the T-Model in the stochastic modeling approach (Englert Tr. 10,182).

We do not object to the decision of not running the RTLC for 50 years because of the cost-saving involved. However, we do not believe that the closeness of the  $M_T$  values predicted by the two models is an appropriate criterion for justifying the use of the T-Model in lieu of the RTLC. As pointed out under cross-examination, the three stochastically varied sets of parameters (see above) affect principally the conditional mortality rate of the egg and larval stages (Englert Tr. 10,183). In order to validly use the T-Model in lieu of the RTLC, it must be shown that the egg and larval conditional mortality rates predicted by the two models are reasonably close under changing environmental and biological conditions. The need for the underlined criterion is obvious, since the stochastic model runs are made under varying environmental and biological conditions. Unfortunately, only two years are available for comparison purposes, 1974 and 1975. Table 3 lists the  $M_E$  values for eggs, the  $M_E$  values for the combined ysl and pysl stages, and the  $M_E$  values for the combined egg and larval stages for 1974 and 1975. The 1974 values are contained in a November 24, 1978 letter from Dr. Kenneth Marcellus to Henry Gluckstern; the 1975 values were given to EPA during cross-examination on the RTLC.

For 1974, the agreement for egg-larvae is extremely good (within 2% of each other); for 1975, the agreement is not as good, with the T-Model prediction being 16% greater than the RTLC prediction. Still, the agreement is reasonably good. However, upon further inspection, it is apparent that the variation in  $M_E$  for eggs-larvae that occurs between the two years for each model is due to the variation in  $M_E$  for the larval stage. For each model,  $M_E$  for eggs remains substantially the same (less than a 15% change). This result is to be expected, since the egg stage, because of its short stage duration, is much less susceptible than the larval stage to changes in power plant impact under varying conditions. Therefore, changing environmental and biological conditions will cause relatively little change in  $M_E$  for eggs. For the larval stage, however, the  $M_E$  predicted by the RTLC increases twofold between 1974 and 1975; for the T-Model, it increases almost fourfold. With respect to a comparison between models, the RTLC, in 1974, predicts a  $M_E$  value for larvae over twice that predicted by the T-Model, whereas in 1975, the two models predict values much closer to each other (within 16%).

Table 3. Egg and larval conditional mortality rates ( $M_E$ ) predicted by the RTLK and the T-Model for 1974 and 1975 due to the operation of Bowline, Roseton, and Indian Point Units 2 and 3 using average projected intake flow rates for the Period 1976 - 2013.

Year	Life stage	$M_E$		Percent change <sup>a</sup>
		RTLK	T-Model	
1974	egg	0.0105	0.0234	-123%
	larvae	0.0231	0.0108	+53%
	egg-larvae	0.0333	0.0339	-1.8%
1975	egg	0.0092	0.0256	-178%
	larvae	0.0488	0.0422	14%
	egg-larvae	0.0576	0.0667	-16%

$$^a \text{Percent change} = \frac{M_E (\text{RTLK}) - M_E (\text{T-model})}{M_E (\text{RTLK})} \times 100$$

Based on the above, it appears that (1) the stochastic variation of the three parameters tested affects changes principally in  $M_E$  for larvae, and (2) the RTLK and T-Model predictions are not in reasonably close agreement for  $M_E$  values for larvae under varying environmental and biological conditions. Granted, this conclusion is based on a comparison between only two years, and within these two years more than just freshwater flow, w-ratios, and temporal and spatial egg distributions were varying. However, these three sets of parameters are important in determining the vulnerability of eggs and larvae to power plant impact. It is, therefore, our opinion that results generated by the T-Model in the stochastic modeling approach cannot be validly used in lieu of the RTLK.

We, therefore, conclude that the analyses and conclusions presented in Section 3-VI of UT-3 do not adequately characterize the variability in power plant impact which can be expected to occur over the lifetime of Bowline Point, Roseton, and Indian Point Units 2 and 3.

### 5. INCORPORATION OF COMPENSATION IN THE ENTRAINMENT CONDITIONAL MORTALITY RATE

In Section 2, we stated that the RTLC predicted a total power plant conditional mortality rate ( $M_T$ ). By definition of a conditional mortality rate,  $M_T$  should not reflect density-dependent processes. If  $M_T$  were affected by the density of the "yoy" in a compensatory manner, then power plant impact, as represented by  $M_T$ , would be underestimated.

Assuming for the purpose of discussion only, the validity of the utilities' arguments concerning compensation, it is our opinion that  $M_E$ , as predicted by the RTLC, is affected by the density of larvae, so that  $M_E$  increases with increasing larval density and decreases with decreasing larval density. Therefore,  $M_T$  is also affected by the density of larvae, and power plant impact, as represented by  $M_T$ , is already partially offset by compensation.

The bases for this statement are:

- (1) The RTLC was calibrated to specific field data in 1974 and 1975 (see Section III), and the utilities claim that compensation was operative during the time the field data were collected (page 3-VII-3 of UT-3).
- (2) The calibration procedure was used to determine appropriate values for natural survival and stage duration to be input to the RTLC for  $ys1$  and  $ps1$ . Stage durations for  $ys1$  and  $ps1$  were chosen so as to result in the RTLC and the field data having peak standing crops of these two life stages at the same time, or as near to the same time as possible.
- (3) Under cross-examination, the utilities' witnesses agreed with EPA counsel that stage durations were dependent upon growth rate, at least in part (Dew Tr. 9873).
- (4) As stated on page 2-IV-52 of UT-3, it is the belief of the utilities that "...density-dependent growth takes place in the very early stages of the first year of life."
- (5) Under cross-examination, a utilities' witness stated that the conditional mortality rate predicted by the RTLC depends in part on the stage durations chosen for  $ys1$  and  $ps1$  (Englert Tr. 9872).

If we denote  $D$  = density of larvae,  $SD$  = duration of the larval life stage,  $G$  = larval growth rate, and  $M$  = larval conditional mortality rate, then we can establish the following relationships (with a positive relationship denoted by  $r > 0$  and a negative relationship denoted by  $r < 0$ ):

$$(1) \quad SD = f_1 (G); \quad r < 0$$

$$(2) \quad G = f_2 (D); \quad r < 0$$

$$(3) \quad M = f_3 (SD); \quad r > 0$$

From these three relationships, the following conclusions may be drawn:

$$(4) \quad SD = f_4 (D); \quad r > 0 \text{ (from the first two relationships), and}$$

$$(5) \quad M = f_5 (D); \quad r > 0.$$

Therefore, given the utilities' claims regarding density-dependent growth, larval conditional mortality rate is a function of larval density. When larval density is high, larval growth rate decreases, larval stage duration increases, and larval conditional mortality rate increases. Conversely, when larval density is low, larval growth rate increases, larval stage duration decreases, and larval conditional mortality rate decreases. Therefore, assuming the validity of the utilities' positions regarding the relationship between growth rate and density,  $M_T$ , as predicted by the RTLC, will be underestimated.

This underestimation occurs because the power plants which operated in 1974 and 1975 reduced larval density, thus causing an assumed increase in growth rate. This assumed increase in larval growth rate resulted in a decrease in the larval stage durations. The decreased larval stage durations were reflected in the field data via shortened time periods between the peak standing crops of eggs,  $ysl$  and  $pysl$ . The larval stage durations input to the RTLC were based on these shortened time periods, through the LMS calibration procedure. Therefore, the larval stage durations input to the RTLC were less than those which would have been input in the absence of the assumed density-dependent growth response to power plant impact. Therefore,  $M_T$  as predicted by the RTLC has been reduced by the operation of the assumed presence of the compensatory mechanism of density-dependent growth. The amount of underestimation will depend on the amount by which the assumed density-dependent growth has reduced  $M_T$ .

## 6. INCLUSION OF THE IMPACTS OF LOVETT UNITS 4 AND 5 AND DANSKAMMER UNIT 4

The total conditional mortality rates predicted by the RTLC and presented in Part 3 of UT-3 reflect the impact of Bowline, Roseton, and Indian Point Units 2 and 3 only. No other power plants operating on the Hudson River have been included in the utilities' impact predictions. The reason for this omission is cited on page 3-II-1 of UT-3: it is the utilities' stated belief that Indian Point Unit 1 and the entire Lovett and Danskammer facilities have operated for a sufficiently long time "... so that their impact is reflected in the ... stock-recruitment curves generated from data covering the period the plants have been operating ...."

An extensive amount of cross-examination was done with respect to investigating the validity of not including those units of Lovett and Danskammer which are expected to continue to operate well into the 1990's (Tr. 9372-9406). As a result of this extensive cross-examination, it was the position of Dr. Englert of LMS that the non-inclusion of Lovett Units 4 and 5 and Danskammer Unit 4 was appropriate. His reason, however, was not the reason stated on page 3-II-1 of UT-3, but rather the utilities' belief that the value of alpha chosen for the long-range estimates of impact was conservatively low.

Under the assumption that the ERE is a valid tool for power plant impact assessment, it is our opinion that the impacts of Lovett Units 4 and 5 and Danskammer Unit 4 should have been included in the estimation of  $M_T$ . To reiterate and expand upon what was brought out under cross-examination, the three bases for our opinion are as follows:

(1) Any alpha value used in the ERE is supposed to represent, according to the utilities, the amount of "compensatory reserve" in the Hudson River striped bass population available to partially offset any new sources of density-independent mortality (sources that are not reflected in the alpha value). Alpha is theoretically supposed to reflect all the density-independent mortality that has already been imposed (and is still being imposed) on the Hudson River striped bass population over the period of time encompassed by the spawner-recruit data pairs.

(2) The number of spawner-recruit data pairs varies from 14 to 21, depending on the Ricker model utilized by the utilities (e.g., 5-year-lag model, multiple-age-spawner model, and "eggs-on-eggs" model) and on the time period considered (e.g., 1950-1975 versus 1955-1975).

(3) Lovett Unit 4, Danskammer Unit 4, and Lovett Unit 5 began operating in 1966, 1967, and 1969, respectively. Therefore, the density-independent mortality associated with each of these units would have been most reflected in the alpha value derived from the 5-year-lag model utilizing data from 1955-1975, and least reflected in the multiple-age-spawner or "eggs-on-eggs"

model of Exhibit UT-58. The maximum and minimum fractions of spawner-recruit data pairs which reflect the impact of each of the three units are given in Table 4.

The following example illustrates what is meant by the number of data pairs which reflect density-independent mortality: Lovett Unit 4 started operation in 1966. Therefore, it first imposed density-independent mortality on the year class spawned in 1966. Utilizing the 5-year-lag model, this mortality is reflected in the 1971 recruit index and the corresponding 1966-1971 spawner-recruit data pair. Likewise, the mortality associated with Lovett Unit 4 is reflected in the 1972 through 1975 recruit indices and the corresponding four spawner-recruit data pairs used in the regression analysis. However, because Lovett Unit 4 started operating in 1966, it did not impact the 1965 or prior year classes. Therefore, the density-independent mortality resulting from the operation of this unit is not reflected in any of the eleven spawner-recruit data pairs prior to 1966 that are used in the 5-year-lag model.

Based on the above discussion, it is quite apparent that, except for Lovett Unit 4 and Danskammer Unit 4 for the 5-year-lag model, very little of the density-independent mortality from Lovett Units 4 and 5 and Danskammer Unit 4 is reflected in any of the alpha values derived from the Ricker spawner-recruit model regressions. Even for the 5-year-lag model, 69 and 75% of the spawner-recruit data pairs do not reflect the impact of Lovett Unit 4 and Danskammer Unit 4, respectively.

As indicated above, it was argued (Englert, Tr. 9405) that the alpha value used in the ERE to predict the long-term reductions in the striped bass population presented in Table 3-VIII-1 ( $\alpha = 4.0$ ) is "... sufficiently conservative to reflect the operation of these earlier power plants." What is meant is that the utilities believe that an alpha value of 4.0 underestimates the "amount of compensatory reserve" in the striped bass population. The utilities, therefore, have admitted that they have used a value for alpha in the ERE which they believe to be incorrect (too low). They also admit that the value for  $M_T$  which they use in the ERE is incorrect (too small), since, given their ERE methodology they should have included Lovett Units 4 and 5 and Danskammer Unit 4 in the estimate of  $M_T$ . If the utilities choose to use the ERE, then they should include Lovett Units 4 and 5 and Danskammer Unit 4 in their estimation of  $M_T$  and input this  $M_T$  into the ERE to obtain a long-term impact prediction. Then, they should (1) indicate why they feel the long-term impact prediction is unrealistically high, if they choose to use an alpha value of 4.0, or (2) do away with the need for explanations by utilizing an alpha value they believe to be correct, assuming that there is a correct alpha value.

Table 4. Fraction of spawner-recruit data pairs from 1955 - 1975 which reflect the impact of Lovett Units 4 and 5 and Danskammer Unit 4

Unit	Year operation started	Number of data pairs in regression		Number of data pairs which reflect density-independent mortality		Fraction <sup>a</sup>	
		5-year lag	Multiple age	5-year lag	Multiple age	5-year lag	Multiple age
Lovett Unit 4	1966	16	17	5	1	0.31	0.06
Danskammer Unit 4	1967	16	17	4	0	0.25	0.00
Lovett Unit 5	1969	16	17	2	0	0.13	0.00

<sup>a</sup>Calculated as the number of data pairs which reflect density-independent mortality divided by the number of data pairs in the regression for the particular model of interest.

## 7. PROPERTIES OF THE RTLC WHICH ARE INCONSISTENT WITH OTHER TESTIMONY BY THE UTILITIES

Because the purpose of the RTLC is to predict a total conditional mortality rate,  $M_T$ , for input to the ERE, those model parameters which most affect  $M_T$  have been of major concern to both the utilities and EPA. However, it should not be forgotten that the RTLC is a biological model, in that it describes the aging (which incorporates the concepts of growth and mortality) and movement of fish during their first year of life. Therefore, we believe that it is appropriate to study the biological features of the RTLC, even if certain of these biological features do not affect the value of  $M_T$  predicted by the RTLC, in order to see if these features are consistent with known biological phenomena and/or with certain biological concepts supported in other testimony submitted by the utilities.

There are at least four properties of the RTLC which are inconsistent with known biological phenomena and/or with other testimony submitted by the utilities. These properties are:

(1) In the RTLC model runs with compensation operative, the utilities use the Beverton-Holt natural mortality rate equation (B-H equation). This equation, which is given on page 3-V-6 of UT-3 (Eq. 3-V-1), defines the natural mortality as a function of "yoy" density at any point in time. Natural mortality rates using this equation are individually calculated for ysl, pysl, juvenile I's, juvenile II's and juvenile III's. It is the only equation in the RTLC which is actually used to determine density-dependent mortality. During cross-examination, it was stated that the stock-recruitment model derived from the B-H equation would be the Beverton-Holt stock-recruitment model (Lawler Tr. 10,120). In testimony presented in Part 2 of UT-3 (page 2-IV-70), the utilities stated that the single stage Beverton-Holt stock-recruitment model (the model which results from integration of the B-H equation used in the RTLC) was not consistent with the known biology of the Hudson River striped bass population. If the utilities argued that their use of the B-H equation in the RTLC does not affect the predictions of impact, they would be correct. We believe, however, that choosing an equation representing "yoy" natural mortality, and utilizing it in combination with the RTLC in a way which is contradictory to one's views on the nature of the stock-recruitment relationship existing in the Hudson River striped bass population, indicates a total lack of concern for consistency in scientific logic.

(2) As indicated above, the B-H equation is applied to each early life stage subsequent to the egg stage. We infer from the way in which the utilities use the B-H equation that they believe that density-dependent mortality is occurring during each of these life stages equally. This latter point is inferred from the utilities' use of a single KO/KE ratio for all life stages after eggs, where the value of KO/KE (KO and KE are two parameters of the B-H equation) is a measure of the amount of compensation (page 3-V-8 of UT-3). In Section 2-VIII-G of UT-3, it was stated that the July - August striped bass juvenile abundance index is a valid measure of

year-class strength (page 2-VIII-19 of UT-3). It was also stated that "... the July - August index should represent subsequent population abundance levels, including the period of recruitment to the fishery" (page 2-VIII-19 of UT-3). If these statements are true, then the primary density-dependent mortality must have occurred prior to the time that the data for this index were collected. Therefore, based on the testimony presented in Section 2-VIII-G, density-dependent mortality should not be applied to the juvenile II and juvenile III stages. In other words, it is the position of the utilities that impingement is mitigated very little, if at all, by density-dependent effects.

(3) During cross-examination (Englert Tr. 9701-2), it was stated that egg production in the RTLC affected larval and juvenile life stage durations very little. In an earlier section of this testimony, it was pointed out that it was the utilities' belief that stage duration and growth rate were negatively correlated (Section 5) and that growth and density of the very early life stages were negatively correlated (Section 5). As a matter of fact, this latter relationship was the basis for the section in Part 2 of UT-3 entitled "The Ricker Model Modified to Reflect Density-Dependent Growth" (2-IV-7(c)), wherein the utilities claimed that stock density (equivalent to egg production in this case) and the growth rate of larvae and early juveniles were negatively related. Thus, once again, it appears that a property of the RTLC is inconsistent with testimony presented in other biological areas by the utilities, since, based on Section 2-IV-7(c) of UT-3, egg production and stage durations should be positively related through the effect of egg production on growth rate. During cross-examination with respect to the RTLC (Englert Tr. 9701), the consultant for the utilities who supervised the development and application of the RTLC, when asked if egg production and stage durations are independent of each other, answered, "Are you asking this as a general biological question or as to how it's handled in the model?" Obviously, the witness readily perceived that there is a lack of correspondence between real-world biological phenomena and the RTLC.

(4) In the stochastic modeling approach presented in UT-3 and discussed in some detail already in this testimony (Section 4), freshwater flow, w-ratios, and temporal and spatial egg distributions were varied stochastically. No other model input parameters were varied. In UT-50, a relationship between growth, freshwater flow and density was presented for "yoy" striped bass; it is the utilities' belief that freshwater flow during the period of February through August affects the growth rate of "yoy" striped bass. It has also been their testimony that "yoy" growth rate and "yoy" survival are related (Lawler Tr. 10,208). Therefore, based on UT-50, it follows that freshwater flow and "yoy" survival are related. In addition, it has been the utilities' testimony, as previously shown (Section V of this testimony) that stage duration and growth rate are related. Therefore, it can be inferred that freshwater flow and stage duration are related. Consequently, the stochastic modeling approach, by varying freshwater flow, while at the same time keeping all the "yoy" life stage durations and survival rates constant, is inconsistent with other testimony presented on behalf of the utilities. Also, assuming the validity of the utilities'

beliefs concerning the interaction between "yoy" growth rate, "yoy" survival and freshwater flow, there is here yet an additional reason to conclude that the results of the stochastic modeling approach (Section 5) are invalid.

Based on the above four inconsistencies, it appears that certain properties of the RTALC contradict specific biological phenomena which the utilities' own consultants contend to be true. In fact, it should be noted that (1) the mechanism of density-dependent growth, the relationship between egg production and growth rate, and the relationship between stock and recruitment which the utilities espouse, and (2) the properties of the RTALC which contradict these utility-espoused biological phenomena, have been presented by the same consultant (Dr. Lawler).

## 8. JUVENILE I ENTRAINMENT

The determination of  $M_E$  by the RTLC for the juvenile I stage depends on two factors: the number of juvenile I's killed by entrainment and juvenile I abundance. This section will examine the validity of the utilities' estimates of the numbers of juvenile I's entrained at Bowline Point, Indian Point Units 2 and 3, and Roseton in 1974 and 1975.

A. Bowline Point

The numbers killed by entrainment at Bowline Point is directly input to the RTLC and was determined, as previously mentioned in Section 3 of this testimony, by the numbers killed per unit volume of power plant intake flow and the average projected power plant flow for the period 1976-2013. The numbers killed per unit volume of water withdrawal were determined by the concentration of juvenile I's found in the discharge samples rather than in the intake samples in 1974 or 1975, because it was believed that the efficiency of capture was markedly higher in the higher velocity discharge. A description of the determination of the numbers killed by entrainment at each plant is contained in Section 3-IV-D(3) of UT-3.

1. 1974 Results

a. Sampling period and number of reliable samples taken. In 1974, no juvenile I's were found in 61 samples collected at the Bowline Point discharge from June 5 - August 2, using a 0.5-meter plankton net (pages 3-IV-65 and 66 of UT-3). During this period, sampling was done once every two weeks. Table 6.2-8 of Exhibit 4 and Fig. 3-VII-19 of UT-3 show the 1974 river standing crop of juvenile I's over time based on TI epibenthic-sled and tucker-trawl data in the Croton-Haverstraw region (the region containing Bowline Point). The data indicate that juvenile I's first appeared during the week beginning on July 1 and last appeared during the week beginning on August 9. Therefore, any sampling done prior to July 1 would not have been expected to capture any juvenile I's at Bowline Point, so that approximately 45% of the 61 samples taken at Bowline would not have been expected to contain juvenile I's. In addition, on page 3-IV-68 of UT-3, it is stated that only 18 reliable samples were taken at the Bowline Point discharge, meaning that only 18 of the 61 samples should have been considered. Of these eighteen, one would assume that a number of them were taken prior to July 1, leaving fewer than 18 samples taken during the time of abundance.

Based on the above discussion, it appears that LMS decreased its chances of capturing juvenile I's at Bowline Point by choosing a sampling period which did not include the entire period when this life stage was present. Therefore, there is a good chance that juvenile I's would have been captured at Bowline Point if sampling had continued into August and if a greater number of reliable samples had been taken during the period of

greatest abundance. This conclusion is made stronger when it is realized that Bowline Point is located in an area of the river (RM 34-38) which contained approximately 23% of the river standing crop of juvenile I's during the entire period when this life stage was present (Exhibit EPA-200, Table III-1).

In addition, there is evidence which suggests that use of a 0.5 meter plankton net in 1974 underestimated the abundance of juvenile I's in the Bowline Point discharge. Studies done at Bowline Point in 1975 by Ecological Analysts (EAI) indicated that abundance of striped bass larvae collected by the larval pump was significantly higher than abundance of striped bass larvae collected by the 0.5-meter plankton net. In addition, these studies indicated that the difference in efficiency of the pump and net was greater as the size of the larvae increased. However, in these studies, the pump sampled the discharge, whereas the net sampled the intake. The intake velocity was more than an order of magnitude lower than the discharge velocity. One would expect that the efficiency of the net would have been higher at the greater discharge velocity. It is not known, however, if the 0.5-meter plankton net would have been as efficient as the larval pump at capturing the larger juvenile I's at the higher discharge velocities. Leithiser et al. (1979) have found that at velocities up to 40 cm/sec, a larval pump is more efficient at capturing larvae of 5-mm total length or greater than is a 0.5-meter plankton net. They also found no correlation between efficiency and velocity, which they indicated could have been due to the "... small range of velocities tested ...." Based on the above studies, indications are that the 0.5-meter plankton net may be a less efficient tool for sampling juvenile I's than the larval pump. Given that a 0.5-meter plankton net was used at Bowline Point in 1974 to determine juvenile I entrainment, there is an additional reason to believe that juvenile I entrainment was underestimated at Bowline Point.

b. Probability of capturing zero juvenile I's at the Bowline Point Discharge in 1974. In Section 3-IV-3(d) of UT-3, an analysis is presented, the stated purpose of which is to determine the probability of capturing zero juvenile I's in a specific number of samples. The reason for this analysis, as testified to by Dr. Englert (Tr. 10,856), is to show that sampling effort at Bowline Point was sufficient so that one could have confidence that the capture of zero juvenile I's in 1974 at Bowline Point was indicative of the true concentration of organisms entrained. In other words, the purpose of the analysis was to attempt to support the implausible contention on the part of the utilities that Bowline Point did not entrain any juvenile I's in 1974. The probability distribution which the utilities chose for the analysis was the Poisson distribution. The results of the analysis indicated that if the true concentration of juvenile I's was 1 per 1000 m<sup>3</sup>, then the probability of capturing zero organisms in 18 samples is 7%. The utilities then concluded that "...there is little chance the measured zero juvenile concentration at Bowline is not close to the actual concentration" (page 3-IV-68 of UT-3). However, these results are contingent upon both the underlying distribution being Poisson and the assumption that each of the 18 samples had an equal probability of capturing juvenile I's.

In our testimony, we have shown that any of the 18 samples taken prior to July 1, 1974 had close to a zero probability of capturing juvenile I's. These samples, therefore, should not have been included in the probability analysis. Secondly, during cross-examination of the utilities, EPA elicited that the actual distribution was not known and that the negative binomial distribution could just as well be the actual underlying distribution (Weiss, Tr. 9548). Mr. Weiss testified that there was no explicit agreement in the literature as to which distribution was the correct one (Weiss, Tr. 9545). Based on the cross-examination and the re-direct testimony presented by the utilities (Weiss, Tr. 9547, Tr. 10, 858), a principle reason that the Poisson distribution was chosen was because it is a one-parameter distribution, with the parameter (sample volume) being known. Therefore, the probability determinations could be made. On the other hand, the negative binomial distribution is a two-parameter distribution, with only one parameter known.

During cross-examination of the utilities, a probability analysis was presented by Mr. Weiss based on the negative binomial distribution being the underlying distribution (EPA Exhibit 156). As mentioned, the negative binomial distribution is a two-parameter distribution, with one parameter being the mean concentration. The second parameter can be defined in a number of ways. In EPA 156, it was defined as the number of patches per sample, with a patch signifying a "globule" of organisms (Weiss, Tr. 9820). A review of EPA-156 indicates that for a given mean concentration of juvenile I's (either 1 or 10 per 1000 m<sup>3</sup>):

- (1) The probability of finding zero organisms in all 18 samples increases as the average number of patches per sample decreases from 0.95 to 0.01.
- (2) The number of juvenile I's contained in a patch (average patch size) increases as the average number of patches per sample decreases from 0.95 to 0.01.
- (3) The product of the average number of patches per sample and the average patch size equals the mean sample concentration of juvenile I's (either 1 or 10 per 1000 m<sup>3</sup>).

Based on the above, if in a system being sampled there are 100 juvenile I's, the mean sample concentration is 1 per 1000 m<sup>3</sup>, and the sample volume is 100 m<sup>3</sup>, then:

- (1) Given an average number of patches per sample of 0.01, there will be 1 patch in the system containing all 100 juvenile I's.
- (2) Given an average number of patches per sample of 1.0, there will be 100 patches in the system, each containing 1 juvenile I.
- (3) The probability of not sampling, in all 18 samples, the 1 patch of 100 organisms will be much higher than the probability of not sampling, in all 18 samples, 1 or more of the 100 patches of 1 juvenile I each.

This last conclusion is intuitively obvious; the likelihood of a fixed number of samples not capturing any juvenile I's increases as the number of "juvenile I patches" in the system decreases. The situation is analagous to finding one big needle in a haystack versus finding many smaller needles in the same haystack, given a fixed number of attempts.

The utilities also testified that:

- (1) The negative binomial distribution approaches the Poisson distribution as the number of patches per sample approaches 0.95 (or 1.00) (Weiss, Tr. 9834).
- (2) The Poisson distribution gives the smallest probability of finding zero organisms in all 18 samples when the mean concentration has any value greater than zero (Weiss, Tr. 9834), which is consistent with the intuitive conclusion made above.

Based on the above, it can be concluded that the Poisson distribution better represents a system with many patches of few organisms, whereas the negative binomial distribution better represents a system containing few patches of many organisms each.

On page 3-IV-64 of UT-3, it is stated that "...due to the patchy distribution of juveniles in the channel...data collected in 1974 and 1975 often showed the presence of juveniles in the plant but not at the river transects, and vice versa." From this statement it can be inferred that juvenile I's tended to form a limited number of patches ("globules") in the near field sampling areas in both 1974 and 1975, rather than a larger number of smaller patches. Thus, these limited number of patches ("globules") of juvenile I's were sometimes found in the plant, but not in the river transects, and at other times, they were found in the river transects, but not in the plant. If they had formed more numerous, smaller patches in the sampling area, the author(s) of the above-quoted statement apparently believed that the juvenile I's would have been found in both locations at the same time.

If juvenile I's tended to concentrate in a small number of patches in the near-field sampling area in 1974 and 1975, where the sampling for determining the number of juvenile I's entrained was conducted, then the negative binomial distribution is more appropriate than the Poisson distribution. If this is true, then not finding any juvenile I's in the assumed fewer than 18 reliable samples taken at Bowline Point during the time that juvenile I's were present in the area is not that unusual, given a non-zero mean concentration in the Bowline Point sampling area. For example, EPA-156 indicates that if the 100 juvenile I's we discussed before were located in 4 patches of 25 organisms per patch, then the probability of capturing zero juvenile I's in 18 samples is 48.7% (Weiss, Tr. 9829). If only 10 samples had a finite probability of capturing juvenile I's at Bowline Point (assuming that 45% of the 18 reliable samples were taken prior to July 1), the probability of capturing zero organisms in all 10 samples is 67.5%.

c. Conclusions. Given that in 1974 (1) sampling for juvenile I entrainment at Bowline Point did not include the entire period of abundance of this life stage, (2) the 0.5-meter plankton net is a very inefficient tool for capturing juvenile I's, and (3) the very good possibility that the relative frequency distribution of juvenile I counts more closely followed a negative binomial distribution than a Poisson distribution, there is every reason to believe that the estimated entrainment of zero juvenile I's at Bowline Point is an underestimate. The amount of the underestimate is very difficult to quantify. However, it should be noted that 4 juvenile I's were collected by the larval pump deployed in the Bowline Point discharge in 1975. Based on these 4 juvenile striped bass collected, an average annual entrainment of 55,091 juvenile I's was estimated by the utilities. Given that (1) the 55,091 estimate for Bowline consisted of approximately one-third of the juvenile I's entrained at all three plants in 1975 and (2)  $M_E$  predicted by the RTLC for the juvenile I stage at all three plants in 1975 was 0.0221,  $M_E$  for juvenile I's at Bowline Point was approximately 0.0074 in 1975. It is quite conceivable that (1) by using the larval pump in 1974, and (2) by taking a greater number of reliable samples during the period of juvenile I abundance at Bowline Point in 1974, that 4 or more juvenile I's would have been collected. Given that the fractions of juvenile I's in the Croton-Haverstraw region in 1974 and 1975 were similar (0.23 versus 0.27; Exhibit EPA-200), the above possibility moves from "quite conceivable" to very probable.

## 2. 1975 Results

On page 3-IV-67 of UT-3, it is stated that starting on June 23 sampling effort used to capture juvenile I's was reduced at Bowline Point. Dr. Englert testified that the reduction in effort coincided with reduction in entrainment, but that the actual number of samples taken was not markedly reduced until July 14 (Englert, Tr. 10,682-3). In 1975, juvenile I's were in the Croton-Haverstraw region during the period June 15 to approximately August 15 (based on epibenthic sled, tucker trawl, and beach seine data), with low abundance during the period of June 15-July 5 and with peak abundance during the week of July 22-26 (Table 6.2-4 of Exhibit UT-4 and Fig. 3-VII-20 of UT-3).

Based on what was learned from the results of 1974, it appears incomprehensible for the utilities' consultant to have decreased the number of days sampled per week starting on June 23 and to have further decreased the number of samples taken starting on July 14 by about a factor of 4 (Englert Tr. 10,682-3). Of the 182 samples taken during the entire sampling period, 132 (72.5%) were taken prior to any appreciable abundance of juvenile I's (Englert, Tr. 10,682-3). It would appear that juvenile I sampling should have been started in earnest on June 15 to determine juvenile I entrainment at Bowline Point, and it should have been concentrated particularly on the period of greatest abundance, July 5-August 2 (Figure 3-VII-20 of UT-3). The only logical explanation for a decrease in sampling effort after June 23 is that the sampling effort which was

decreased had as its primary purpose not the capturing of juvenile I's, but the capturing of ysl and pysl. The significant decline of pysl abundance coincided with the week of June 15-22 (Table 6.2-3 of Exhibit UT-4).

Based on the above, it appears that juvenile I entrainment at Bowline Point was underestimated in 1975, perhaps markedly, particularly when it is noted that RM 34-38 contained approximately 27% of the standing crop of juvenile I's (Exhibit EPA-200).

In 1975, as already mentioned in Section 8.A.1.c, four juvenile I's were collected in the discharge. From these data, LMS estimated an average annual entrainment of 55,091 juvenile I's. Therefore, underestimating the numbers caught by 4 fish would mean that the conditional mortality rate predicted by the RTLC at Bowline Point under 1975 conditions was underestimated by 100% and should have been approximately 0.0148, rather than 0.0074 (See Section 8.A.1.c of this testimony).

Reduction in sampling effort by LMS in 1975, when juvenile I's were still in the Bowline Point area in appreciable abundance and had not even attained their maximum abundance, may have caused a marked underestimation in the conditional mortality rate of juvenile I's at this plant in 1975.

#### B. Indian Point

In both 1974 and 1975, sampling was conducted in the Indian Point discharge canal using a 0.5-meter plankton net. Based on the above discussion for Bowline Point, use of this sampling gear may have resulted in an underestimation in the numbers of juvenile I's caught in both years, and thus, in the juvenile I entrainment conditional mortality rate in both years.

#### C. Roseton

In 1974, sampling was conducted at the discharge using a 0.5-meter plankton net. Based on the above discussion for Bowline Point, the use of this sampling gear may have resulted in an underestimation in the numbers of juvenile I's caught in 1974 and, thus, in the juvenile I entrainment conditional mortality rate. Considering that the utilities estimated zero juvenile I's entrained in 1974, the likelihood that an underestimate occurred appears plausible.

## 9. SPATIAL DISTRIBUTION ANALYSIS - YSL AND PYSL

A. Importance

The importance of the spatial distributions predicted by the RTLC for ysl and pysl was stated during cross-examination and redirect examination a number of times (Englert, Tr. 9979-81; Englert, Tr. 10,124; Englert, Tr. 10,855). Spatial distribution is one of the important factors which determine vulnerability to entrainment, and therefore, entrainment conditional mortality rate. The importance of spatial distribution was made clear in a discussion between EPA Counsel and Dr. Lawler, one of the utilities' expert witnesses (Lawler, Tr. 10,152-6). Dr. Lawler stated that, given the methodology used in the RTLC to predict the number of ysl and pysl killed by entrainment (f-factor approach), the RTLC would not accurately predict entrainment impact, if the spatial distribution predicted by the RTLC was different than the spatial distribution indicated by the actual field data. It should be pointed out that in 1974 the ysl and pysl stages contributed almost 50% to the total entrainment conditional mortality rate (0.0231 of 0.0492; see Tables 2 and 3), while in 1975 these two stages contributed a little over 60% (0.0488 of 0.0783; see Tables 2 and 3). Therefore, it is crucial that the RTLC predict accurately the spatial distributions of the larval stages, particularly in the power plant segments, in order to accurately predict entrainment conditional mortality rates.

The spatial distributions as predicted by the RTLC for the ysl and pysl stages over time are primarily determined by three factors: the spatial distribution of the egg stage, the ysl and pysl vertical migration preferences, and the hydrodynamic simulation of the tidal flow of the Hudson River. Values for the first two factors are input data to the RTLC. The tidal flow regime (both in time and space) predicted by the RTLC is the principal means of longitudinal transport in the model for the egg, ysl and pysl stages. By comparing the ysl and pysl longitudinal spatial distributions predicted by the RTLC with those indicated by the field data, the validity of the hydrodynamic simulation, and thus the accuracy of the  $M_E$  predictions, can be ascertained. In most cases, the only way that a model's accuracy can be determined is to compare model predictions of an event to the observed event itself (Englert, Tr. 9417). Comparison of egg spatial distributions will not be made owing to (1) the short duration of the egg stage (2-3 days), and (2) the fact that the weekly spatial distributions of eggs determined from the field data are directly input to the RTLC. As a result, the RTLC most certainly generates egg spatial distributions almost identical to those based on the field data.

B. Field Data and Model Runs Chosen

Since the purpose of comparing the longitudinal spatial distributions is to determine the accuracy of the hydrodynamic simulation and the accuracy of the RTLC predictions of  $M_E$  for ysl and pysl, we chose to examine the

spatial distributions generated by the RTLC when it was run with (1) no power plants operating and no compensation under "1974 conditions," and (2) no power plants operating and no compensation under "1975 conditions." These two runs will be designated as the "equilibrium year" runs for 1974 and 1975. These are the two sets of spatial distributions that the power plants are applied to and that, therefore, are pertinent to the determination of  $M_E$ .

The field data chosen for the comparison were those collected by Texas Instruments in its riverwide ichthyoplankton sampling programs of 1974 and 1975.

### C. Time Period and River Segmentation

Since TI developed weekly density estimates for  $ys1$  and  $pys1$  in 12 river regions, and since the RTLC outputs numbers of  $ys1$  and  $pys1$  in each of these river regions, we compared corresponding weekly RTLC and "TI" spatial distributions over the entire 12 regions. Table 5 contains the mile points associated with each of the 12 TI regions. Particular emphasis was given to the regions containing the power plants. Only those weeks during which abundance of  $ys1$  and  $pys1$  was relatively high were chosen for comparison, since during this time (1) almost all the entrainment occurs, and (2) the field data are more accurate. We have defined a week of relatively high abundance in terms of the RTLC. A week of relatively high abundance is any model week, which at any time during the simulation during that week has a riverwide standing crop of the particular life stage under analysis which is greater than or equal to 10% of the riverwide peak standing crop of that life stage, as predicted by the RTLC. Although the weeks chosen were based on the RTLC, these weeks were equally appropriate to the field data. As a matter of fact, when the TI weekly standing crop estimates (see Subsection D.1 below) were totaled over the entire period of life stage abundance in the river, the weeks of relatively high abundance, as defined above, accounted for 97% or more of the total.

### D. Method of Calculation of Spatial Distribution

#### 1. TI Field Data

The methodology used to calculate the fraction of the standing crop of  $ys1$  and  $pys1$  in each of the 12 TI sampling regions for each week of abundance during the years 1974 and 1975 is presented by Exhibit EPA-200. The fractions calculated are based entirely on TI's determinations of regional concentrations over time and space and TI's estimates of the volumes of the individual regions. No adjustments were made to the data. These weekly fractions were calculated and provided by Dr. J. Boreman and were used in the comparison with the RTLC predictions.

Table 5. Milepoints corresponding to TI regions and location of power plants

Region			
Number	Name	Milepoint	Power plant
1	Yonkers	14-23	
2	Tappan Zee	24-33	
3	Croton-Haverstraw	34-38	Bowline Point
4	Indian Point	39-46	Indian Point
5	West Point	47-55	
6	Cornwall	56-61	
7	Poughkeepsie	62-76	Roseton
8	Hyde Park	77-85	
9	Kingston	86-93	
10	Saugerties	94-106	
11	Catskill	107-124	
12	Albany	125-140	

## 2. RTLC

For each week of relatively high abundance, we calculated the fractions of the standing crop in the 12 TI regions. These fractions correspond to the average weekly regional standing crop relative to the average weekly standing crop summed over all regions. These fractions appear in Tables 6-9. It should be noted that Region 3 contains Bowline Point, Region 4 contains Indian Point and Region 7 contains Roseton (Region 1 is the most downstream region and Region 12 is the most upstream region).

### E. Comparability of Longitudinal Spatial Distributions Resulting from the Equilibrium - Year Model Runs and the TI Field Data

LMS designed the RTLC output for spatial distribution to be consistent with the TI sampling regions in order to facilitate comparisons of the RTLC predictions to TI's field data. However, before comparing the observed (TI field data) and predicted (RTLC) spatial distributions, we had to be convinced that the two sets of spatial distributions we chose to compare were, indeed, comparable, particularly in the regions containing the power plants. Certain properties of either the field data or the RTLC spatial distributions tend to cause differences in the two sets of distributions which would exist independent of the accuracy of the RTLC simulation. However, based on the discussion presented immediately below in subsections E.1 through E.4, the total magnitude of the effects of these properties is small enough so that the two sets of spatial distributions can be compared for purposes of examining the accuracy of the RTLC simulation.

#### 1. Depletion in Power Plant Regions

When comparing the spatial distributions predicted by the RTLC in the "equilibrium" year to the TI field data, it must be noted that the spatial distributions based on the field data in 1974 and 1975 are affected by the power plants' withdrawal of  $ys1$  and  $pys1$ . However, based on the ETM's maximum predicted  $M_E$  value for actual power plant operating conditions in 1974 and 1975 through the  $pys1$  stage (Exhibit EPA-200, Section 8), we believe that the observed spatial distributions of  $ys1$  were affected very little by power plant operation. On the other hand, the fraction standing crop of  $pys1$  in the Indian Point region in both 1974 and 1975 may have been affected by the operation of Indian Point and Lovett. It should be pointed out that the withdrawal of  $ys1$  and  $pys1$  by the power plants would tend to underestimate the fraction of these two life stages in the regions containing the power plants, owing to a depletion effect. Therefore, the field data slightly underestimated the fraction of  $ys1$  and  $pys1$  in the regions containing the power plants, and as a result, the field data slightly underestimated the vulnerability of these two life stages to entrainment. This depletion effect can be verified by comparing the spatial distributions of the RTLC corresponding to (1) the "equilibrium" year, and

Table 6. Fraction of the standing crop ( $FSC_{i,j}$ ) of yolk-sac larvae predicted by the RTLC by week and by river region for 1974

TI river region, j	Week, i (Week 1 starts April 29) <sup>a</sup>						All weeks ( $FSC_j$ )
	2	3	4	5	6	7	
1	0	0.001	0.018	0.067	0.119	0.069	0.045
2	0.001	0.004	0.029	0.075	0.111	0.061	0.051
3	0.007	0.032	0.109	0.149	0.122	0.056	0.108
4	0.128	0.240	0.270	0.241	0.174	0.085	0.235
5	0.694	0.516	0.317	0.155	0.080	0.106	0.269
6	0.155	0.157	0.111	0.064	0.033	0.074	0.092
7	0.014	0.039	0.064	0.061	0.085	0.174	0.063
8	0	0.008	0.022	0.041	0.073	0.144	0.035
9	0	0.003	0.027	0.057	0.070	0.085	0.039
10	0	0.001	0.019	0.051	0.072	0.069	0.034
11	0	0	0.012	0.033	0.051	0.063	0.023
12	0	0	0.003	0.007	0.011	0.014	0.005

<sup>a</sup>  $\sum_{j=1}^{12} FSC_{i,j} = 1.000$  for each week.

Table 7. Fraction of the standing crop ( $FSC_{i,j}$ ) of post yolk-sac larvae predicted by the RTLK by week and by river region for 1974

TI river region, j	Week, i (Week 1 starts April 29) <sup>a</sup>							All weeks ( $FSC_j$ )
	5	6	7	8	9	10	11	
1	0.038	0.086	0.150	0.163	0.186	0.217	0.177	0.140
2	0.035	0.075	0.124	0.133	0.149	0.172	0.140	0.115
3	0.048	0.076	0.099	0.093	0.091	0.093	0.072	0.086
4	0.201	0.213	0.182	0.155	0.141	0.125	0.099	0.173
5	0.363	0.266	0.169	0.146	0.128	0.099	0.096	0.189
6	0.189	0.138	0.087	0.083	0.073	0.050	0.063	0.101
7	0.111	0.092	0.071	0.088	0.087	0.073	0.116	0.085
8	0.009	0.019	0.025	0.036	0.038	0.038	0.060	0.028
9	0.003	0.013	0.028	0.032	0.032	0.036	0.052	0.025
10	0.002	0.013	0.034	0.036	0.038	0.047	0.063	0.029
11	0.001	0.008	0.025	0.029	0.031	0.041	0.051	0.023
12	0	0.002	0.006	0.006	0.007	0.009	0.011	0.005

<sup>a</sup>  $\sum_{j=1}^{12} FSC_{i,j} = 1.000$  for each week.

Table 8. Fraction of the standing crop ( $FSC_{i,j}$ ) of yolk-sac larvae predicted by the RTLC by week and by river region for 1975

TI river region, j	Week, i (Week 1 starts May 11) <sup>a</sup>				All weeks ( $FSC_j$ )
	2	3	4	5	
1	0.009	0.007	0.018	0.034	0.011
2	0.010	0.013	0.029	0.031	0.017
3	0.045	0.058	0.081	0.040	0.061
4	0.327	0.266	0.248	0.200	0.271
5	0.378	0.352	0.295	0.327	0.342
6	0.114	0.137	0.157	0.209	0.140
7	0.069	0.110	0.115	0.134	0.104
8	0.022	0.025	0.023	0.014	0.023
9	0.012	0.011	0.008	0.004	0.010
10	0.008	0.010	0.010	0.003	0.010
11	0.005	0.008	0.013	0.004	0.009
12	0.001	0.002	0.003	0.001	0.002

<sup>a</sup>  $\sum_{j=1}^{12} FSC_{i,j} = 1.000$  for each week.

Table 9. Fraction of the standing crop ( $FSC_{i,j}$ ) of post yolk-sac larvae predicted by the RTLC by week and by river region for 1975

TI river region, j	Week, i (Week 1 starts May 11) <sup>a</sup>					All weeks ( $\bar{FSC}_j$ )
	4	5	6	7	8	
1	0.035	0.056	0.082	0.113	0.139	0.072
2	0.039	0.052	0.071	0.094	0.113	0.065
3	0.066	0.069	0.075	0.081	0.082	0.073
4	0.229	0.219	0.206	0.180	0.163	0.208
5	0.293	0.255	0.235	0.208	0.194	0.248
6	0.148	0.143	0.136	0.123	0.114	0.137
7	0.133	0.147	0.137	0.144	0.128	0.139
8	0.026	0.028	0.028	0.028	0.027	0.027
9	0.012	0.010	0.010	0.011	0.013	0.011
10	0.011	0.010	0.009	0.009	0.013	0.010
11	0.008	0.009	0.008	0.008	0.011	0.008
12	0.002	0.002	0.002	0.002	0.002	0.002

<sup>a</sup>  $\sum_{j=1}^{12} FSC_{i,j} = 1.000$  for each week.

(2) the case of power plants operating with composite f-factors of 1.0 for the ysl and pysl stages.

## 2. River Regions vs Model Segments

In the RTLC, the power plants withdraw the organisms, not in concentrations corresponding to the TI river regions, but in concentrations corresponding to smaller model segments within the regions. However, we believe that the regional fractions are still valid for use in determining the accuracy of the RTLC's prediction of  $M_E$ .

Indian Point, for example, is in Region 4, which extends from milepoint 39 to milepoint 46. However, Indian Point withdraws organisms at a concentration associated with the model segment extending from milepoint 42 to milepoint 44. The standing crop in Region 4 is determined as follows (this method applies to all other regions as well): the standing crop in any model segment at any time  $t$  is determined by first taking the product of the upper layer segment concentration and the corresponding upper layer volume, and then adding this product to the product of the lower layer concentration and lower layer volume. The total standing crops in model segments 21, 22 and 23 and two-thirds of the standing crop in Segment 20, as calculated above, are then allocated to Region 4, since all of Segments 21, 22 and 23 are located in Region 4, while two-thirds of Segment 20 (based on longitudinal length) is located in Region 4. Thus, based on length, Segment 21 contributes 25% to the standing crop of Region 4. Therefore, if the field data indicate that 20% of the standing crop of ysl in Week 2, for example, is located in Region 4, and the RTLC predicted 10%, this discrepancy strongly indicates that the concentrations of organisms in Segments 20-23 are all underestimated by the RTLC. It would be difficult, in this example, to imagine the concentration in Segment 21, which contains Indian Point, not being underestimated, while the concentrations in Segments 20, 22 and 23 were underestimated.

This type of conclusion is even more true for the region containing Bowline Point (Region 3). Region 3 is only 5 miles in length (whereas Region 4 is 8 miles in length) and includes all of Segments 24 (Bowline Point) and 25 and 1/2 of Segment 26. Therefore, based on length, Segment 24 contributes 40% to the standing crop of Region 3.

However, for Region 7 (which includes all of Segments 9-13, 20% of Segment 8, and 50% of Segment 14), Segment 12 (Roseton) contributes, based on length, approximately 13% to the standing crop of Region 7. Thus, for Region 7, there is a greater possibility that differences between the RTLC and TI estimates of fractional standing crops may not denote real differences in Segment 12. However, if the differences in fraction standing crop between the field data and the RTLC predicted values are substantial, we would conclude that the RTLC predictions of fraction standing crop in Segment 12, and all the other segments contributing to the standing crop of Region 7, are inconsistent with the field data.

### 3. Allocation of Standing Crops to Regions

Actual "TI" regional volumes are not used in the RTLC to compute standing crops in the TI regions; rather, the volumes of the 29 model segments are utilized. In addition, as noted above, if two-thirds of a segment's length is in a region, then two-thirds of the segment's standing crop is allocated to the region. It is, therefore, assumed that (1) the regional volumes are the sum of the segment volumes which they contain, and (2) the fraction of a segment's standing crop in a Region is directly proportional to the fraction of the segment's length in a region. Except for Regions 1 and 12, both these assumptions are reasonable. For Region 12, assumption 1 is not valid, since Region 12 extends to milepoint 140, well beyond the RTLC boundary of milepoint 130. However, since Region 12 contains an insignificant fraction of ysl and pysl (less than 0.1% based on both the RTLC predictions and on TI's field estimates), the violation of assumption (1) will have no effect on the comparability between the RTLC and "TI" spatial distributions. Region 1 violates both assumptions, since it is allocated all of Segment 29's standing crop, but only extends down to milepoint 14, whereas Segment 29 extends to milepoint 10. A comparison between the volumes of Segments 28 plus 29 and Region 1 (part of Segment 28 is in Region 1) indicates that the standing crop in Region 1, as predicted by the RTLC, may be overestimated by as much as 30% due to LMS effectively allocating all of Segment 29's volume to Region 1. However, this overestimate of standing crop should not affect the validity of the results of the spatial distribution analysis presented here, since the relative regional volumes will remain essentially the same.

### 4. Compensation

The utilities' claim that the TI field data reflect the operation of compensation. However, the RTLC model runs chosen for this analysis do not have compensation operative. This difference does not create a problem, since in running the RTLC with compensation, LMS determines the amount of compensation from the total riverwide concentration of each life stage. Therefore, there are no segment or regional differences in natural mortality within life stages, and the relative spatial distributions predicted by the RTLC with compensation operative or not operative are identical. Of course, the actual field data may, in fact, reflect some spatial differences in natural mortality within the ysl and/or pysl stages in 1974 and/or 1975. However, there is no way of quantifying the magnitude of such an effect on the spatial distributions of the ysl or pysl stages, if such an effect, indeed, existed. We can only assume that the effect, if it existed, would have had little impact on the spatial distributions.

### F. Analysis

The method used in this testimony to quantify the effect that differences in the spatial distributions predicted by the RTLC and observed to exist in the river in 1974 and 1975 had on the RTLC predicted values of ME is given below.

For a given composite f-factor, the number of ysl or pysl entrained in Week i will depend on the fraction of the weekly standing crop present in Week i in the regions containing the power plants, on the fraction of the total standing crop (over all weeks) of ysl or pysl present in Week i, and on the power plant flow rates. Let us define the following terms:

$FSC_{i,j}$  = fraction of the standing crop of ysl (or pysl) in Week i in Region j.

$W_i$  = fraction of the total standing crop of ysl (or pysl) present during all the weeks of relatively high abundance, which was present in Week i.

$Q_{i,j}$  = power plant intake flow in Week i in Region j.

$P_{i,j}$  =  $FSC_{i,j} W_i Q_{i,j}$  (1)  
= index of impact in Week i of relatively high abundance of a power plant located in Region j.

$P_j$  =  $\sum_i P_{i,j}$  (2)  
= index of impact of a power plant located in Region j over all the weeks of relatively high abundance.

$P$  =  $\sum_j P_j$  (3)  
= index of impact of all power plants (i.e., over all regions) over all weeks of relatively high abundance.

Tables 6-9 present all  $FSC_{i,j}$  values predicted by the RTLC for ysl and pysl for 1974 and 1975. Corresponding values based on the TI field data were derived by the methods specified in Exhibit EPA-200. Tables 10 and 11 present the  $W_i$  values for both the RTLC and TI temporal distributions for ysl and pysl in 1974 and 1975. A review of Tables 10 and 11 shows, that for the most part, the weeks of high  $W_i$  values for the RTLC simulations and the TI field data coincide. However, the field data indicate a shorter time period of high standing crops, particularly in 1975 when 94% of the ysl standing crop and 94% of the pysl standing crop were present in a two-week period. Therefore, the index of power plant impact may be affected somewhat by differences in temporal distributions, particularly in 1975.

Tables 12 and 13 present  $P_j$  and  $P$  values for ysl and pysl for 1974 and 1975 for the RTLC predictions and the TI field data. The numbers in the column labelled "% Difference" were calculated as follows:

$$\% \text{ Difference} = \frac{P_j \text{ (RTLC)} - P_j \text{ (TI)}}{P_j \text{ (TI)}} \times 100 \quad (4)$$

Table 10. Fraction of the total standing crop (over all weeks of relatively high abundance and all river regions) of yolk-sac larvae and post yolk-sac larvae present during each week of relatively high abundance in 1974 as calculated from RTALC predictions and from TI field data

Life stage	Week, i	$W_i^a$	
		RTLC	TI
ysl	2	0.03	0.01
	3	0.15	0.01
	4	0.34	0.15
	5	0.32	0.44
	6	0.14	0.19
	7	0.02	0.20
	pysl	5	0.08
6		0.21	0.10
7		0.27	0.30
8		0.21	0.38
9		0.14	0.13
10		0.07	0.02
	11	0.02	0.01

<sup>a</sup>For each life stage for the RTALC predictions and for the TI field data,  $\sum_i W_i = 1.00$ .

Table 11. Fraction of the total standing crop (over all weeks of relatively high abundance and all river regions) of yolk-sac larvae and post yolk-sac larvae present during each week of relatively high abundance in 1975 as calculated from RTLc predictions and from TI field data

Life stage	Week	$W_i^a$	
		RTLc	TI
ysl	2	0.21	0.05
	3	0.49	0.52
	4	0.26	0.42
	5	0.04	0.01
pysl	4	0.25	0.52
	5	0.30	0.42
	6	0.22	0.03
	7	0.14	0.02
	8	0.09	0.01

<sup>a</sup>For each life stage for the RTLc predictions and for the TI field data,  $\sum_i W_i = 1.00$ .

Table 12. Indices of impact for ysl and pysl in 1974 based on RTLC and TI spatial distributions

Life stage	Plant	$P_j^a$		% Difference <sup>b</sup>
		RTLC	TI	
ysl	Bowline Point	0.0753	0.0657	+ 15%
	Indian Point	0.2939	0.1454	+ 102%
	Roseton	0.0419	0.2487	- 83%
	Total <sup>c</sup>	0.4111	0.4598	- 11%
pysl	Bowline Point	0.0794	0.0608	+ 31%
	Indian Point	0.2358	0.3246	- 27%
	Roseton	0.0623	0.1364	- 54%
	Total <sup>c</sup>	0.3775	0.5218	- 28%

$$^a P_j = \sum_i P_{i,j} = \sum_i FSC_{i,j} W_i Q_{i,j}. \text{ See Eqs. (1) and (2).}$$

$$^b \% \text{ Difference} = \frac{P_j \text{ (RTLC)} - P_j \text{ (TI)}}{P_j \text{ (TI)}} \times 100. \text{ See Eq. (4).}$$

$$^c \text{Total} = P = \sum_j P_j. \text{ See Eq. (3).}$$

Table 13. Indices of impact for ysl and pysl in 1975 based on RTLC and TI spatial distributions

Life stage	Plant	$P_j^a$		% Difference <sup>b</sup>
		RTLC	TI	
ysl	Bowline Point	0.0437	0.0792	- 45%
	Indian Point	0.3416	0.2943	+ 16%
	Roseton	0.0690	0.0861	- 20%
	Total <sup>c</sup>	0.4543	0.4596	- 1%
pysl	Bowline Point	0.0668	0.0861	- 22%
	Indian Point	0.2839	0.4347	- 35%
	Roseton	0.1019	0.1005	+ 1%
	Total <sup>c</sup>	0.4526	0.6213	- 27%

$$^a p_j = \sum_i P_{i,j} = \sum_i FSC_{i,j} W_i Q_{i,j}. \text{ See Eqs. (1) and (2).}$$

$$^b \% \text{ Difference} = \frac{P_j (\text{RTLC}) - P_j (\text{TI})}{P_j (\text{TI})} \times 100.$$

$$^c \text{Total} = P = \sum_j P_j.$$

A review of the P values in Tables 12 and 13 (column headed "Plant" and rows headed "Total") shows that in three out of the four cases (ys1 for 1974; pys1 for 1974 and 1975), the RTLC predicts longitudinal spatial distributions which result in an underestimation of power plant impact. The underestimation is on the order of 10% for ys1 in 1974 and 25-30% for pys1 in 1974 and 1975.

After analyzing the results presented in Tables 6-13, it is apparent that the discrepancy between the RTLC-based  $P_j$  values and the TI-based  $P_j$  values is a consequence of the RTLC transporting too far downriver the ys1 and pys1 stages in 1974 and the pys1 stage in 1975. A more detailed discussion follows:

### 1. 1974

a. ys1. A review of Tables 12 and 13 shows that the RTLC greatly overestimated (all discussions in this section refer to under - or over - estimates of impact as a function of longitudinal spatial distributions only) the impact of Indian Point, greatly underestimated the impact of Roseton, and slightly overestimated the impact of Bowline Point. Interestingly, based on the RTLC  $P_j$  values, Roseton had the least impact of the three plants, while based on the TI  $P_j$  values, it had the greatest impact. From Table 6, we see that the RTLC predicted 6.3% (over all weeks) of the ys1 standing crop in the region containing Roseton; in contrast, the TI field data indicated 35.3% (Exhibit EPA-200, Table III-1). In addition, based on Table 6, the RTLC predicted 70.8% (over all weeks) of the standing crop below milepoint 56; in contrast, the TI field data indicated only 34.7% (Exhibit EPA-200, Table III-1). This excessive downriver transport by the RTLC, besides causing an underestimation in Region 7, resulted in an  $FSC_j$  value of 23.5% in the region containing Indian Point (Table 6), whereas the field data indicated only 11% (Exhibit EPA-200, Table III-1). Although the % Difference between the RTLC and TI P values is not large (-11%; see Table 12), the close agreement is a result of the fortuitous circumstance of two large errors (% Difference values of Indian Point and Roseton) almost cancelling each other.

b. pys1. A review of Table 12 indicates poor agreement between the RTLC and TI  $P_j$  values for all three plants. The RTLC spatial distribution resulted in an underestimate of impact at Indian Point and Roseton and an overestimate of impact at Bowline Point. A review of Table 7 indicates that the RTLC predicted 25.5% of the standing crop of pys1 (over all weeks) in the two most downstream regions. This result is contrary to the field data, which showed only 3.9% (Exhibit EPA-200, Table III-1) in these two regions. The unrealistic downstream transport of pys1 by the RTLC was even more pronounced in the most downstream region (Region 1). TI found only 0.1% (Exhibit EPA-200, Table III-1) of the standing crop in Region 1, whereas the RTLC predicted 14.0%. As a result, the fraction of pys1 located in the regions containing Indian Point and Roseton was greatly underestimated; the sum of the  $FSC_j$  values for these two regions was 0.258 for the RTLC and 0.425 for "TI" (Exhibit EPA-200, Table III-1).

2. 1975

a. ysl. Except for Bowline Point, the RTALC and "TI"  $P_j$  values agree fairly well. Considering that Indian Point accounted for 70 to 75% of the total P value, the close agreement takes on added importance.

A review of the two sets of spatial distributions in Regions 4 and 7 reveals the reason for the close agreement. During the peak periods of ysl abundance, Weeks 3 and 4 (May 25 and June 1), the fractions of the standing crop contained in Region 4 were, for the RTALC, 0.266 and 0.248, respectively (Table 8). The corresponding TI values were 0.208 and 0.252. For Region 7, the RTALC predicted values were 0.110 and 0.115 for Weeks 3 and 4, respectively (Table 8). The corresponding TI values were 0.139 and 0.114. The close agreement between the RTALC and TI values in these two weeks is depicted in Figures 8 and 9 (see Section 9.F.3, which starts on the next page). The reason for the close agreement was mostly likely due to the short stage duration for yolk-sac larvae of 8 days in 1975 as opposed to 15 days in 1974. The hydrodynamic simulation had less time to generate disparities between the RTALC predictions and the observed (TI) spatial distributions.

b. pysl. The RTALC and TI  $P_j$  values for Roseton were within 1% of each other; this is excellent agreement. However, a review of the two sets of spatial distributions and Figure 12 indicates that the close agreement is not due to agreement between the two sets of spatial distributions over the time of greatest abundance, as was the case with Indian Point above. Agreement appears to have been caused by offsetting over- and under-estimates of the RTALC fractional standing crops in Region 7, in that the underestimate in the  $FSC_{i,j}$  value during Week 4 was balanced by the overestimates during Weeks 5, 6, and 7.

With respect to Indian Point (Region 4), agreement between  $P_j$  values is poor. The RTALC markedly underestimated the index of impact, as is shown by the % Difference value of -35% (Table 13). Considering that the  $P_j$  value for Indian Point accounts for 60-70% of the total P value, this estimate takes on added importance. A review of the two sets of spatial distributions and Figure 11 reveals the reason for the RTALC's underestimation of the index of impact. During Week 5, which had a  $W_j$  value of 0.30 for the RTALC and 0.42 for "TI" (Table 11), the  $FSC_{i,j}$  values for Region 4 were 0.219 for the RTALC (Table 9) and 0.584 for TI. As was the case in 1974, the RTALC transported an unrealistically high fraction of pysl into the two most downstream segments (13.7% for the RTALC versus 2.7% for TI). This problem is even more pronounced in Region 1, the most downstream segment, where the RTALC predicted 7.2% (Table 9) and TI indicated 0.5% (Exhibit EPA-200, Table III-1).

Based on the above discussion, we conclude that the RTALC hydrodynamic simulation of the tidal flow of the Hudson River was unable to accurately predict the longitudinal spatial distribution over time of the ysl and pysl stages in 1974 and of the pysl stage in 1975. Consequently, we cannot have confidence that the RTALC would be able to accurately predict the

longitudinal spatial distribution of these two life stages in any other years. These conclusions, in turn, reduce our confidence that the RTLTC can be relied upon to accurately predict power plant impacts for 1974, 1975, or any other years, since as pointed out in Section 9.A, prediction of power plant impact depends on spatial distributions.

### 3. Graphical Comparisons of Patterns of Movement

The previous discussion was concerned primarily with a comparison of the RTLTC- and TI- based fraction standing crops of ysl and pysl in the three power plant regions over time. The dual purpose of the comparison was (1) to ascertain the ability of the RTLTC to accurately predict ysl and pysl longitudinal spatial distributions, and (2) to ascertain if the RTLTC underestimated or overestimated the fraction standing crop in the three power plant regions and power plant impacts.

Additional insight can be gained with respect to the ability of the RTLTC to accurately simulate the movement of ysl and pysl by studying the changes in the fraction standing crop over time in the regions containing the power plants. Figures 1-12 depict the temporal changes in fraction standing crop (i.e., patterns of movement) for ysl and pysl as predicted by the RTLTC and as observed in the field over the time of greatest abundance for the regions containing the power plants. One would expect to find reasonably good agreement between the RTLTC predictions and the observed patterns of movement, if the RTLTC accurately simulated the movement of these two life stages. For example, one would expect that if the field data showed a substantial increase or decrease in fraction standing crop of ysl during one week, then the RTLTC would predict this substantial increase or decrease as well. A review of Figures 1-12 indicates poor agreement between the RTLTC predicted patterns of movement and the actual observed patterns of movement. In order to quantify the extent of disagreement, one or the other of the following two criteria was applied. First, if in going from Week i to Week i+1, the change was in one direction (i.e., an increase or a decrease) for the RTLTC predictions but in the opposite direction for the TI field data, the particular comparison was tallied as a case of disagreement. Second, if in going from Week i to Week i+1, the change was in the same direction for the RTLTC predictions and TI field data, the following two-part criterion for disagreement was applied. The first part of the criterion is that for the time series (that is the RTLTC predictions or the observed TI field data) having the smaller relative change of fractional standing crop between Week i and Week i+1, the percent change had to be less than 25%. The second part of the criterion is that for the time series having the larger relative change, the change had to be a factor of two or more, that is a 100% or more increase or a 50% or more decrease. Both parts of this second criterion had to be satisfied in order for the comparison to be tallied as a case of disagreement.

ORNL-DWG 82-7328ESD

## REGION 3

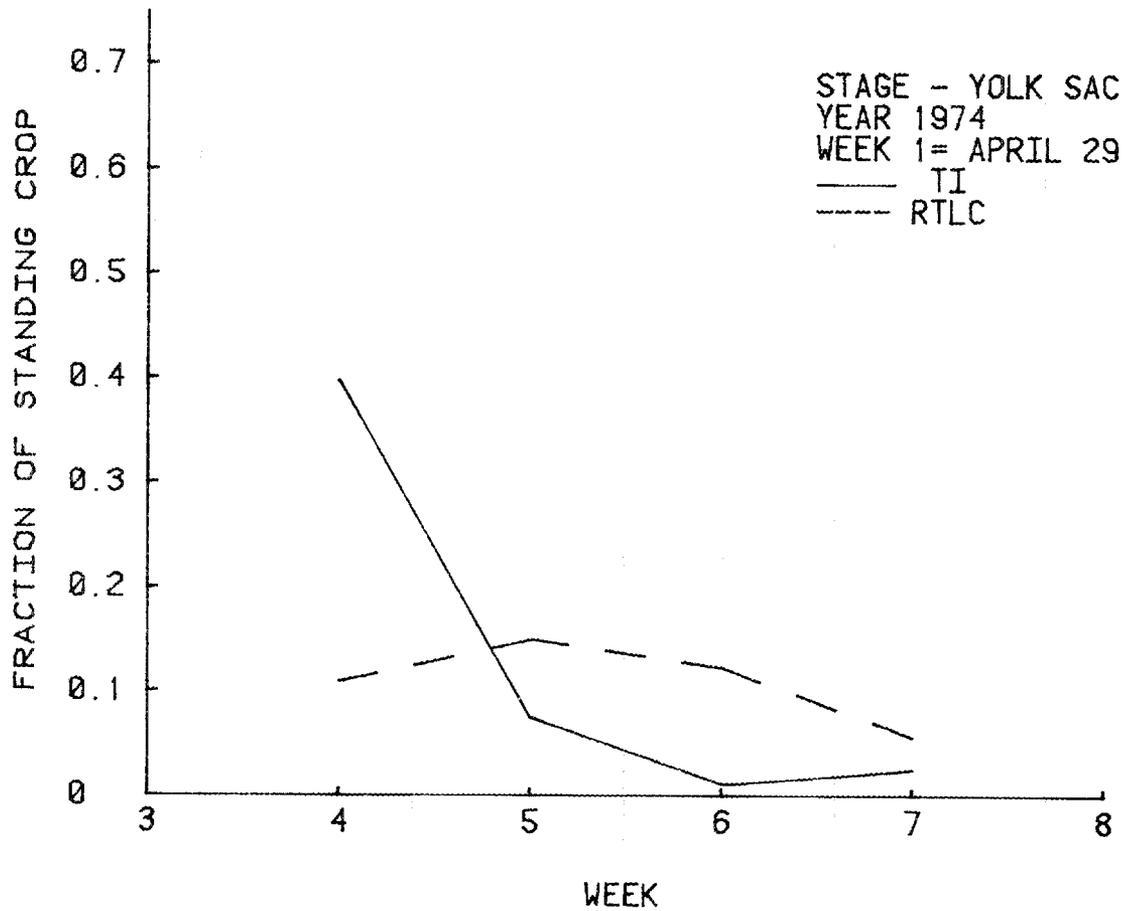


Figure 1. Comparison of observed (TI) and predicted (RTLC) temporal changes in fraction standing crop ( $FSC_{i,j}$ ) of ysl during the weeks of relatively high abundance in 1974 in Region 3.

REGION 4

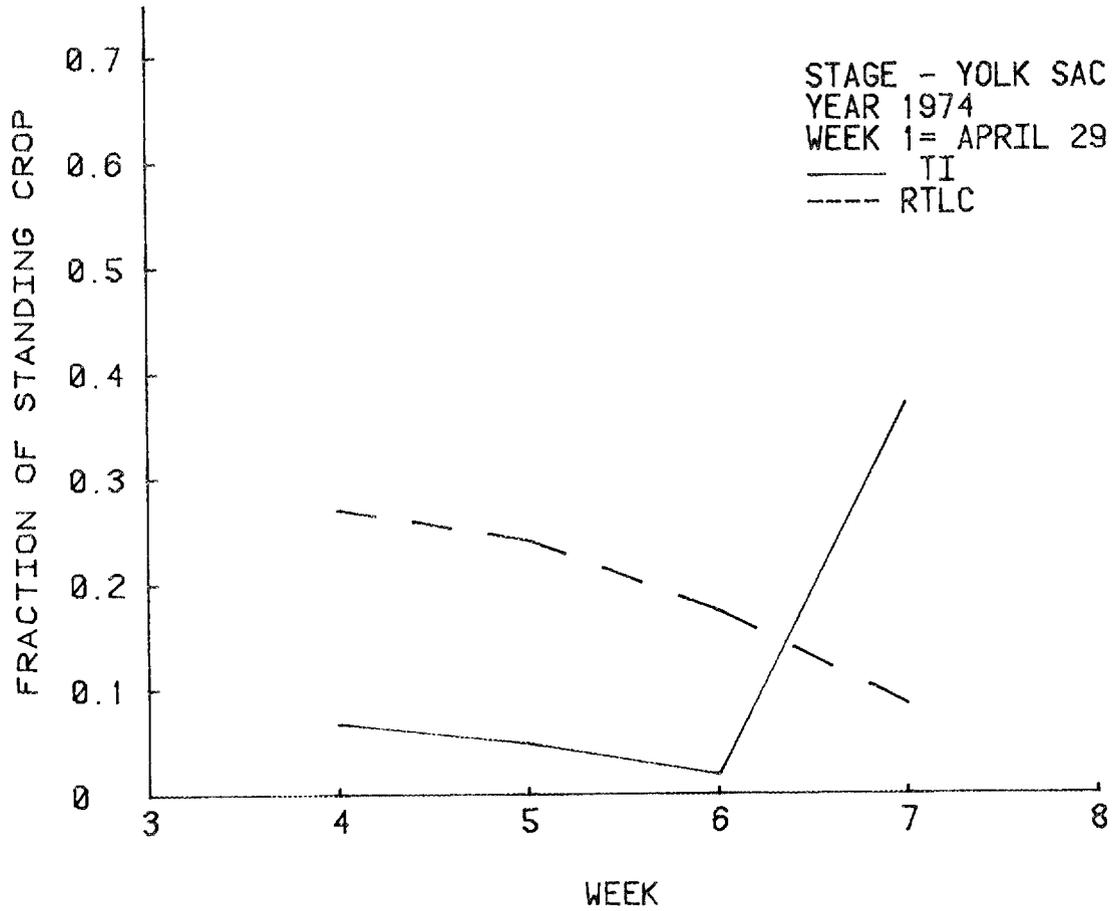


Figure 2. Comparison of observed (TI) and predicted (RTL) temporal changes in fraction standing crop ( $FSC_{i,j}$ ) of ysl during the weeks of relatively high abundance in 1974 in Region 4.

ORNL-DWG 82-7330ESD

## REGION 7

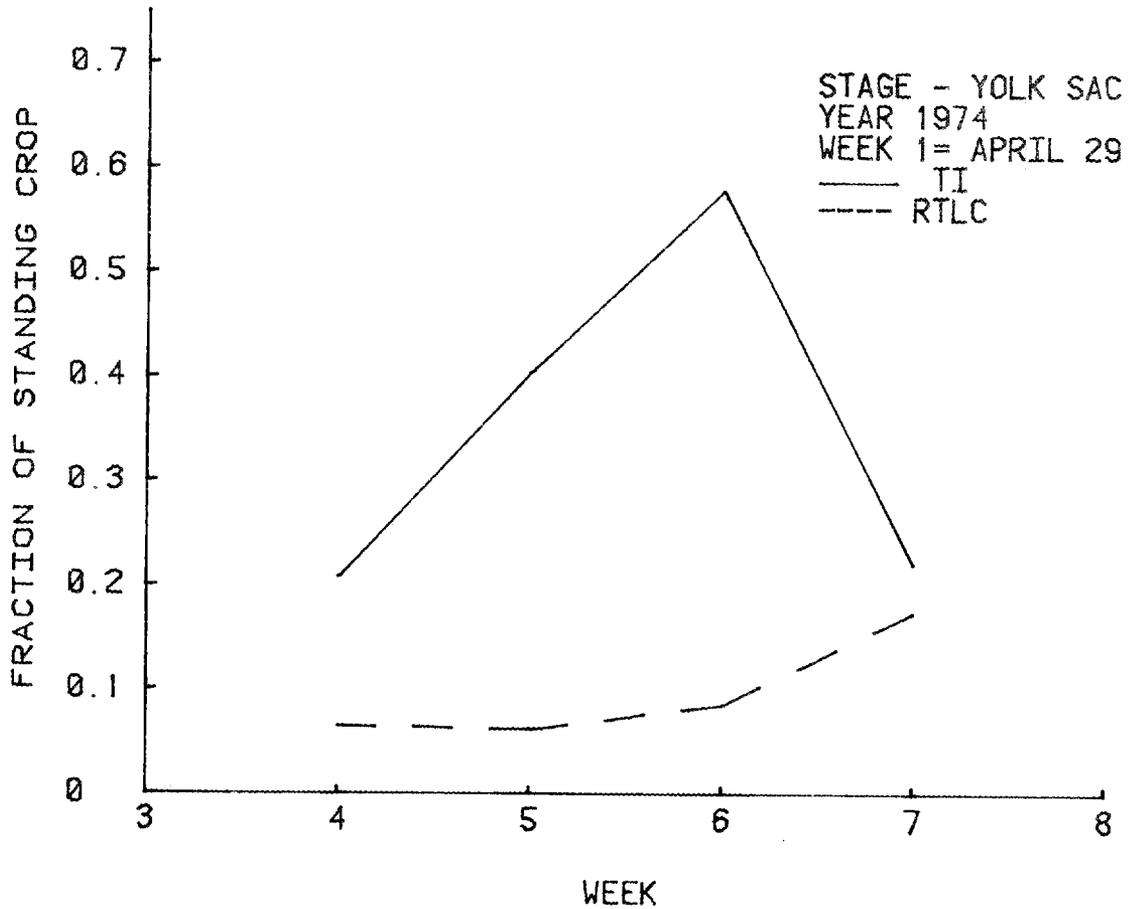


Figure 3. Comparison of observed (TI) and predicted (RTL) temporal changes in fraction standing crop ( $FSC_{i,j}$ ) of ysl during the weeks of relatively high abundance in 1974 in Region 7.

ORNL-DWG 82-7331ESD

REGION 3

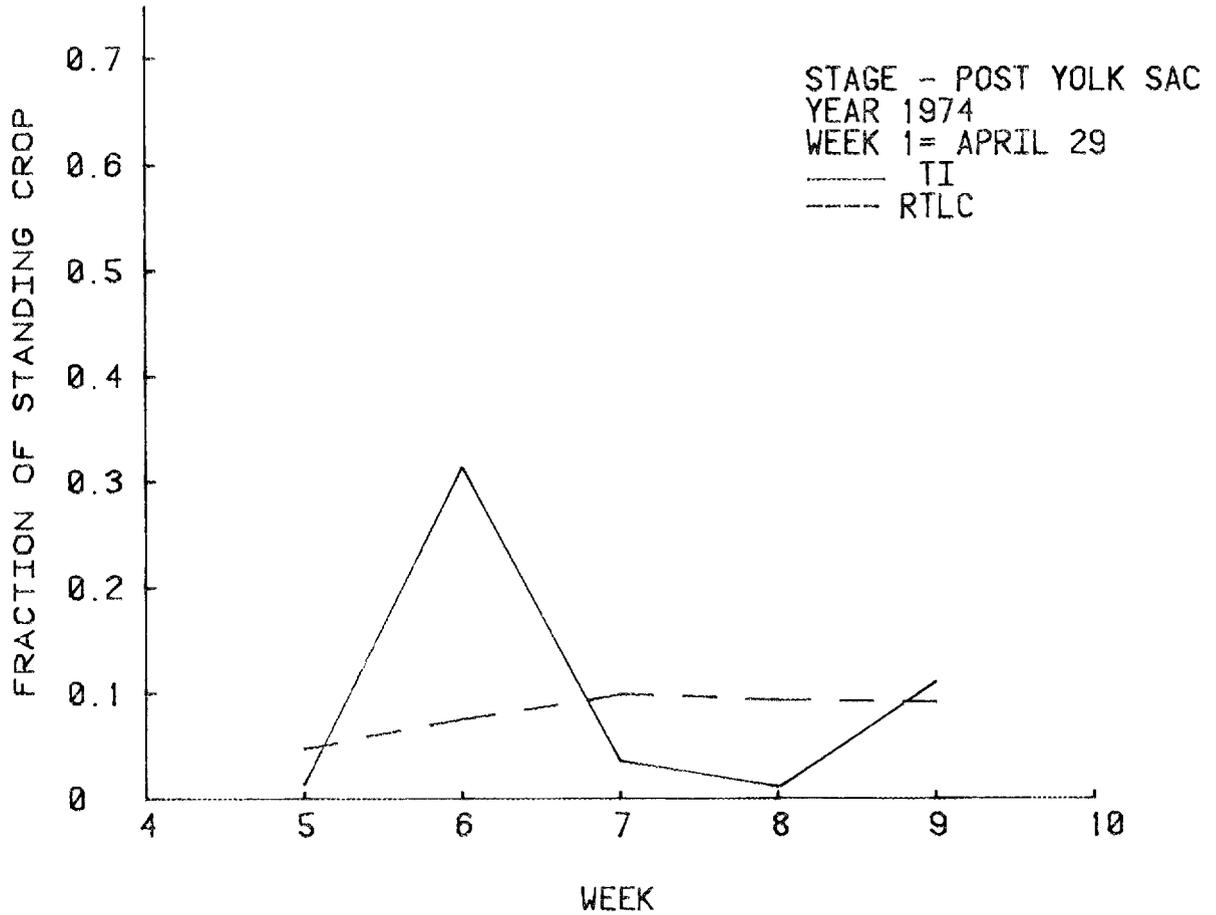


Figure 4. Comparison of observed (TI) and predicted (RTL) temporal changes in fraction standing crop ( $FSC_{i,j}$ ) of pysl during the weeks of relatively high abundance in 1974 in Region 3.

ORNL-DWG 82-7332ESD

## REGION 4

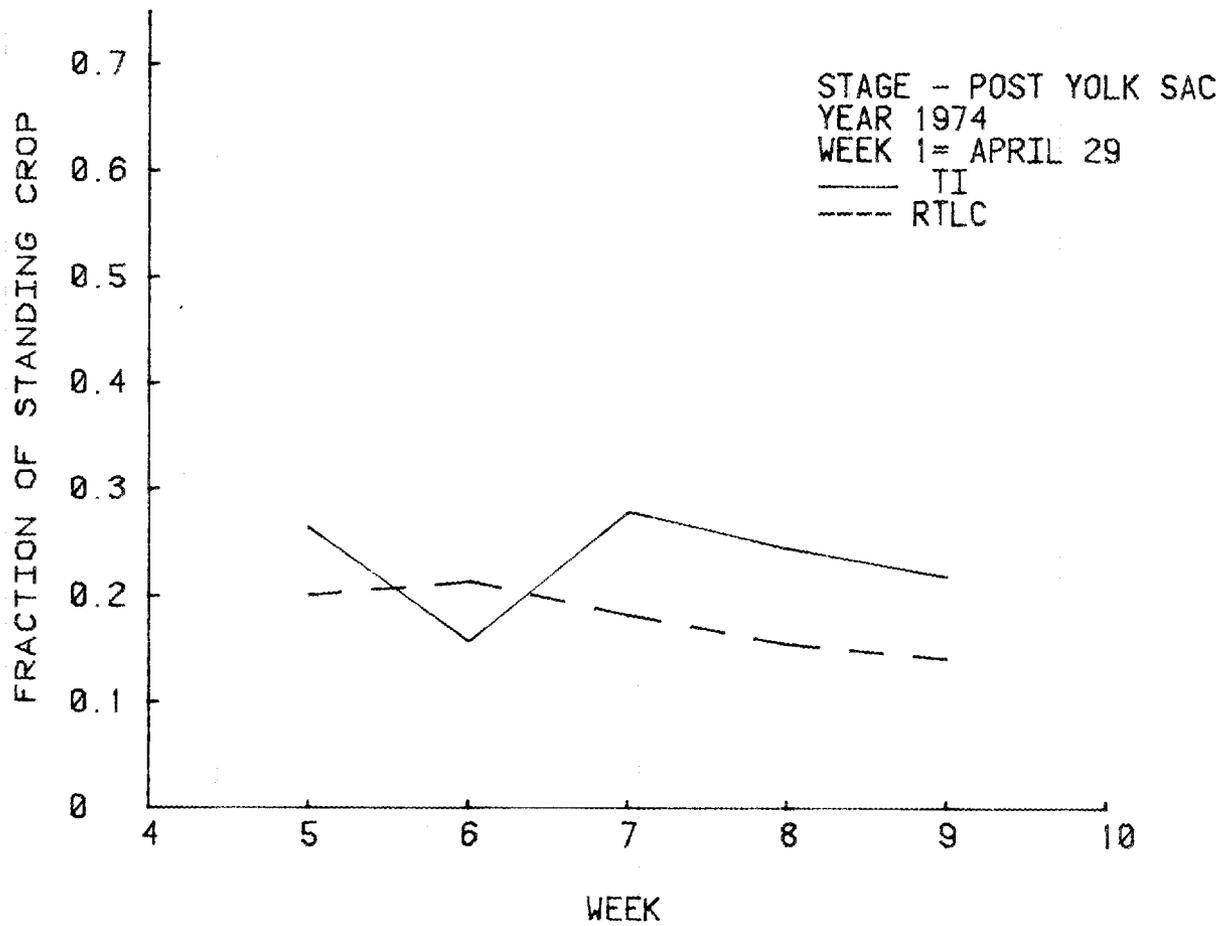


Figure 5. Comparison of observed (TI) and predicted (RTL) temporal changes in fraction standing crop ( $FSC_{i,j}$ ) of pysl during the weeks of relatively high abundance in 1974 in Region 4.

ORNL-DWG 82-7333ESD

## REGION 7

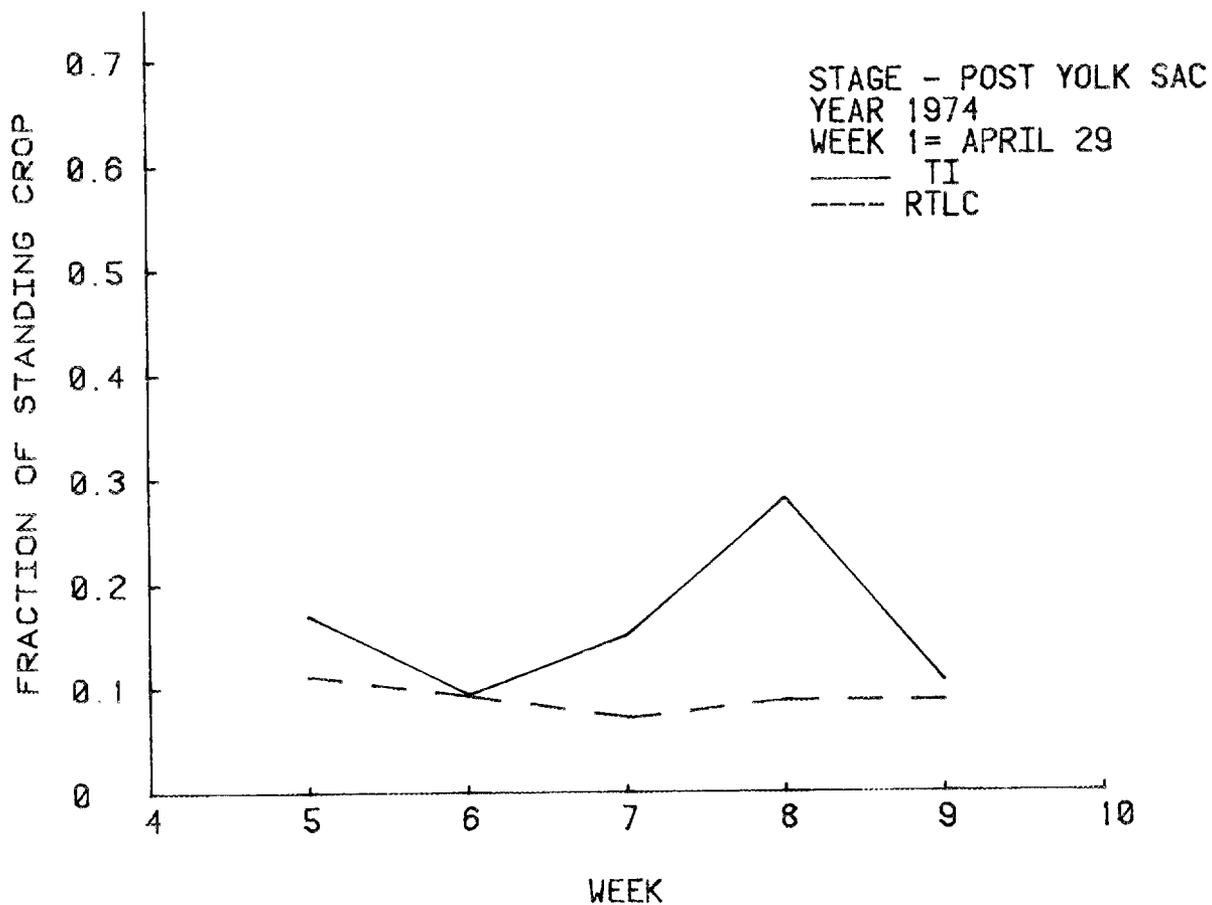


Figure 6. Comparison of observed (TI) and predicted (RTL) temporal changes in fraction standing crop ( $FSC_{i,j}$ ) of pysl during the weeks of relatively high abundance in 1974 in Region 7.

ORNL-DWG 82-7334ESD

REGION 3

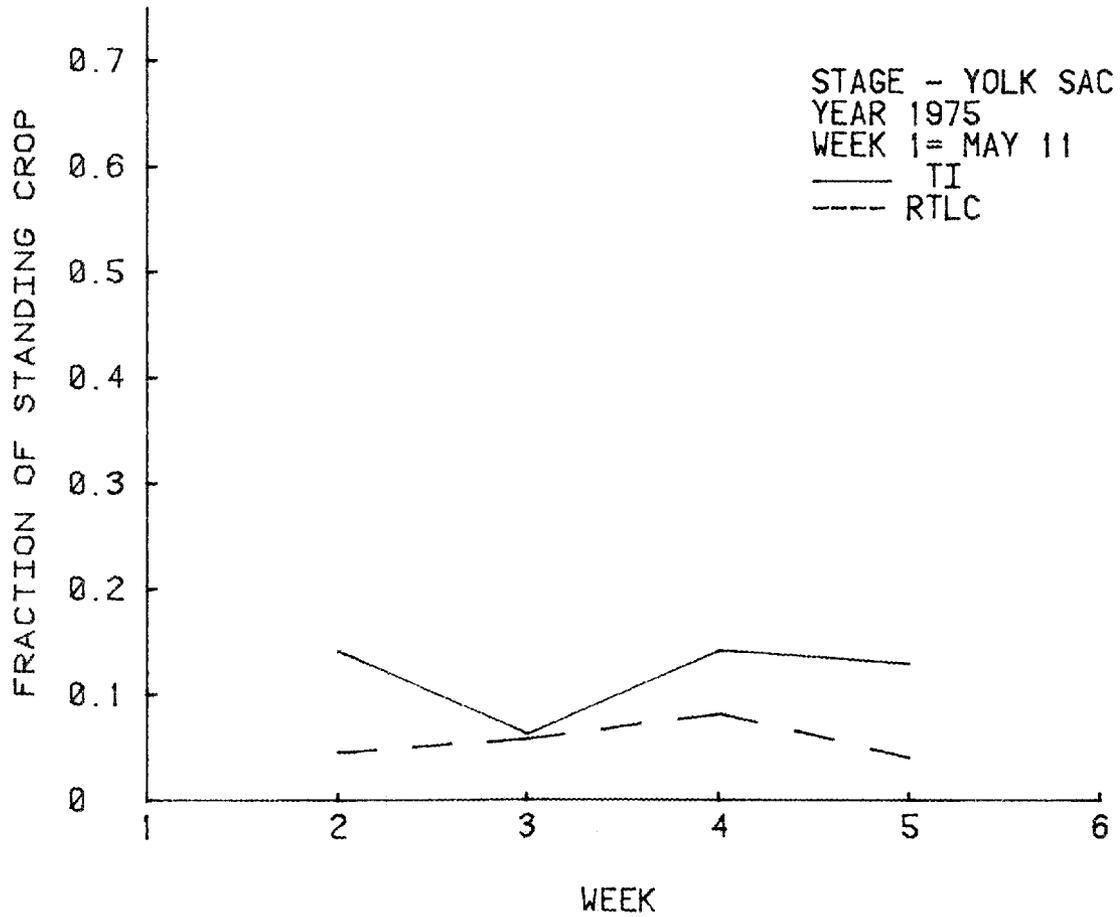


Figure 7. Comparison of observed (TI) and predicted (RTL) temporal changes in fraction standing crop ( $FSC_{i,j}$ ) of ysl during the weeks of relatively high abundance in 1975 in Region 3.

ORNL-DWG 82-7335ESD

## REGION 4

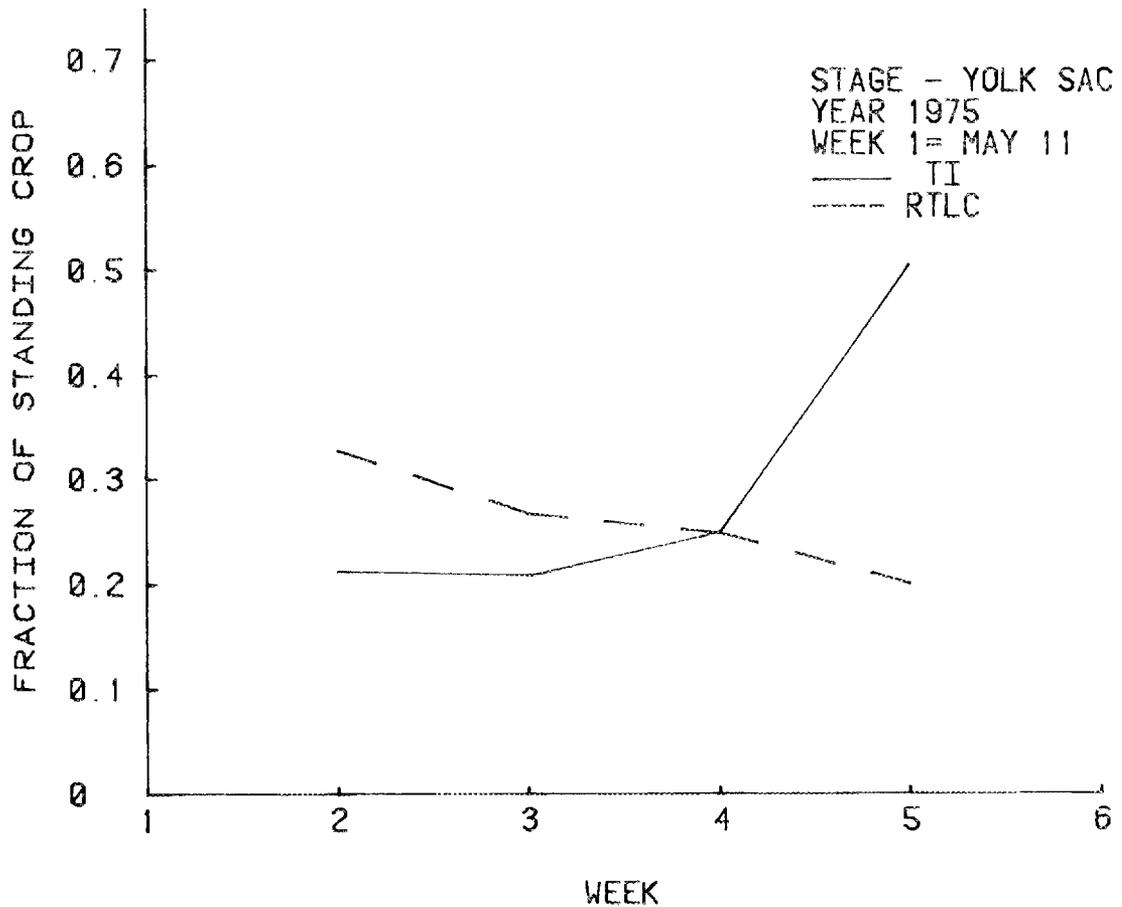


Figure 8. Comparison of observed (TI) and predicted (RTL) temporal changes in fraction standing crop ( $FSC_{i,j}$ ) of ysl during the weeks of relatively high abundance in 1975 in Region 4.

REGION 7

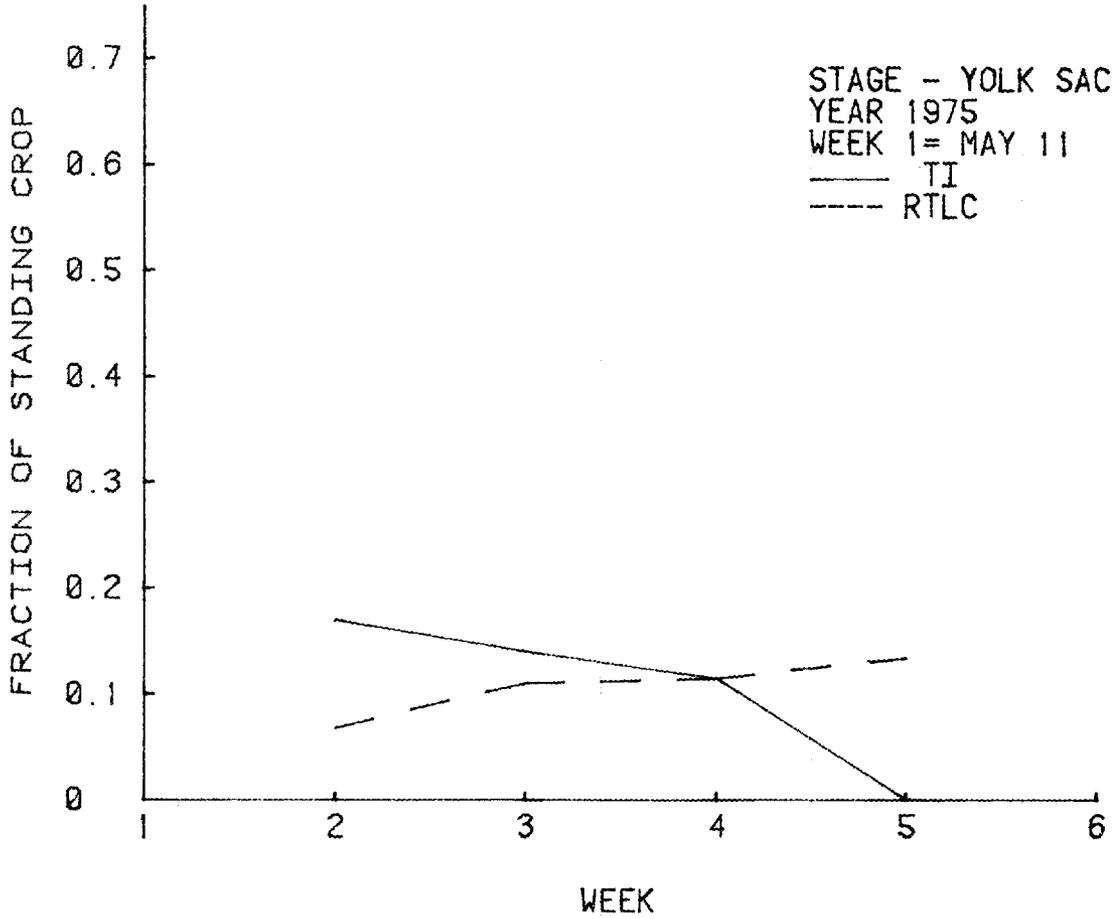


Figure 9. Comparison of observed (TI) and predicted (RTL) temporal changes in fraction standing crop ( $FSC_{i,j}$ ) of ysl during the weeks of relatively high abundance in 1975 in Region 7.

ORNL-DWG 82-9350ESD

## REGION 3

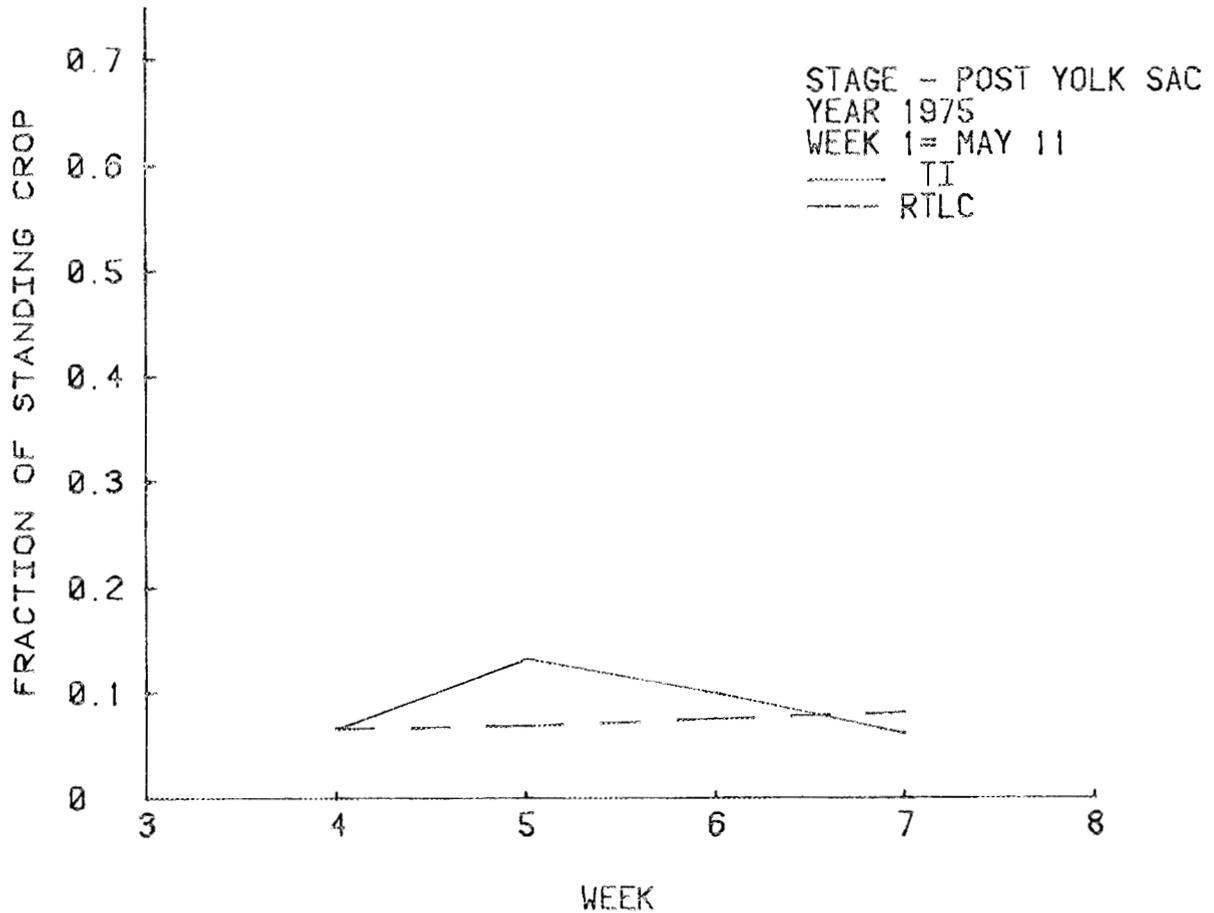


Figure 10. Comparison of observed (TI) and predicted (RTL) temporal changes in fraction standing crop ( $FSC_{i,j}$ ) of pysl during the weeks of relatively high abundance in 1975 in Region 3.

ORNL-DWG 82-9351ESD

## REGION 4

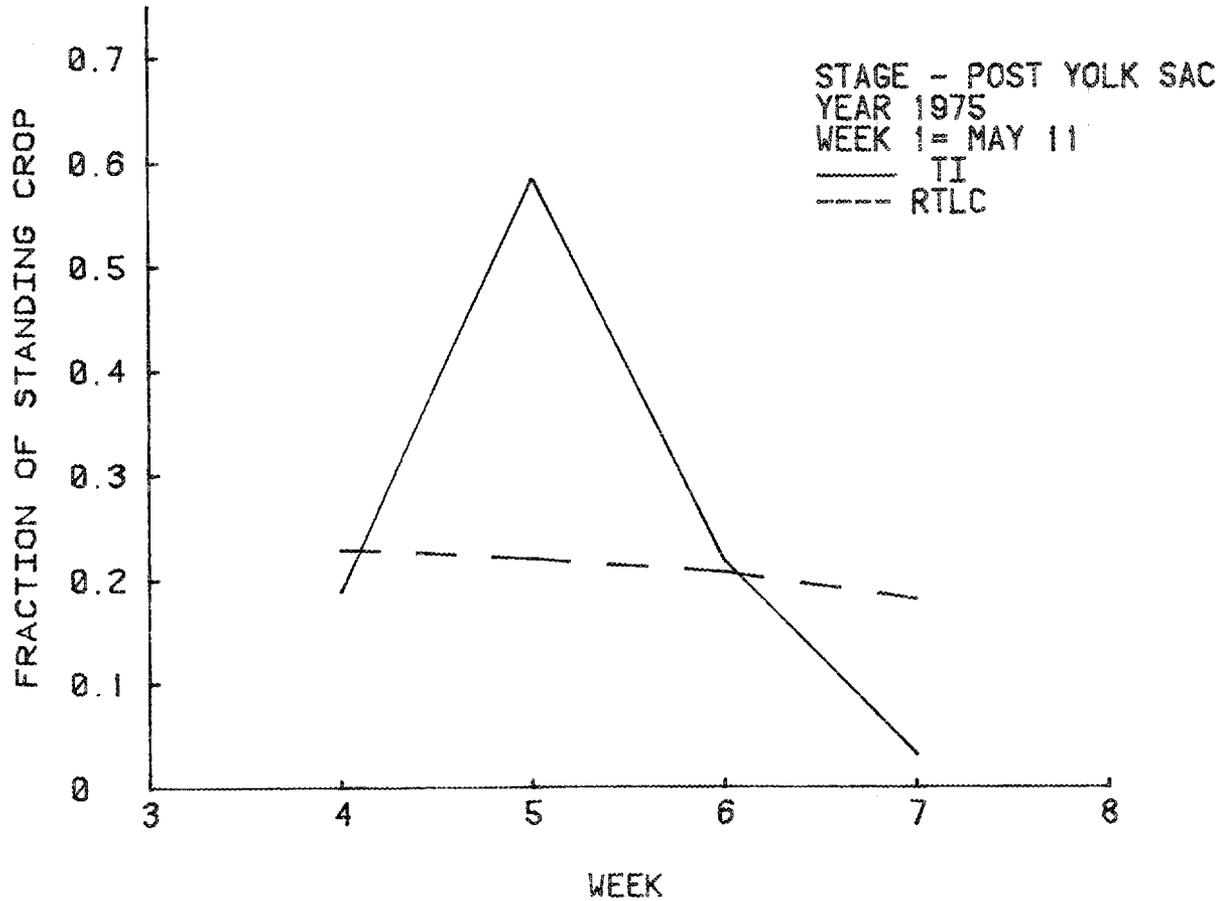


Figure 11. Comparison of observed (TI) and predicted (RTL) temporal changes in fraction standing crop ( $FSC_{i,j}$ ) of pysl during the weeks of relatively high abundance in 1975 in Region 4.

ORNL-DWG 82-9352ESD

REGION 7

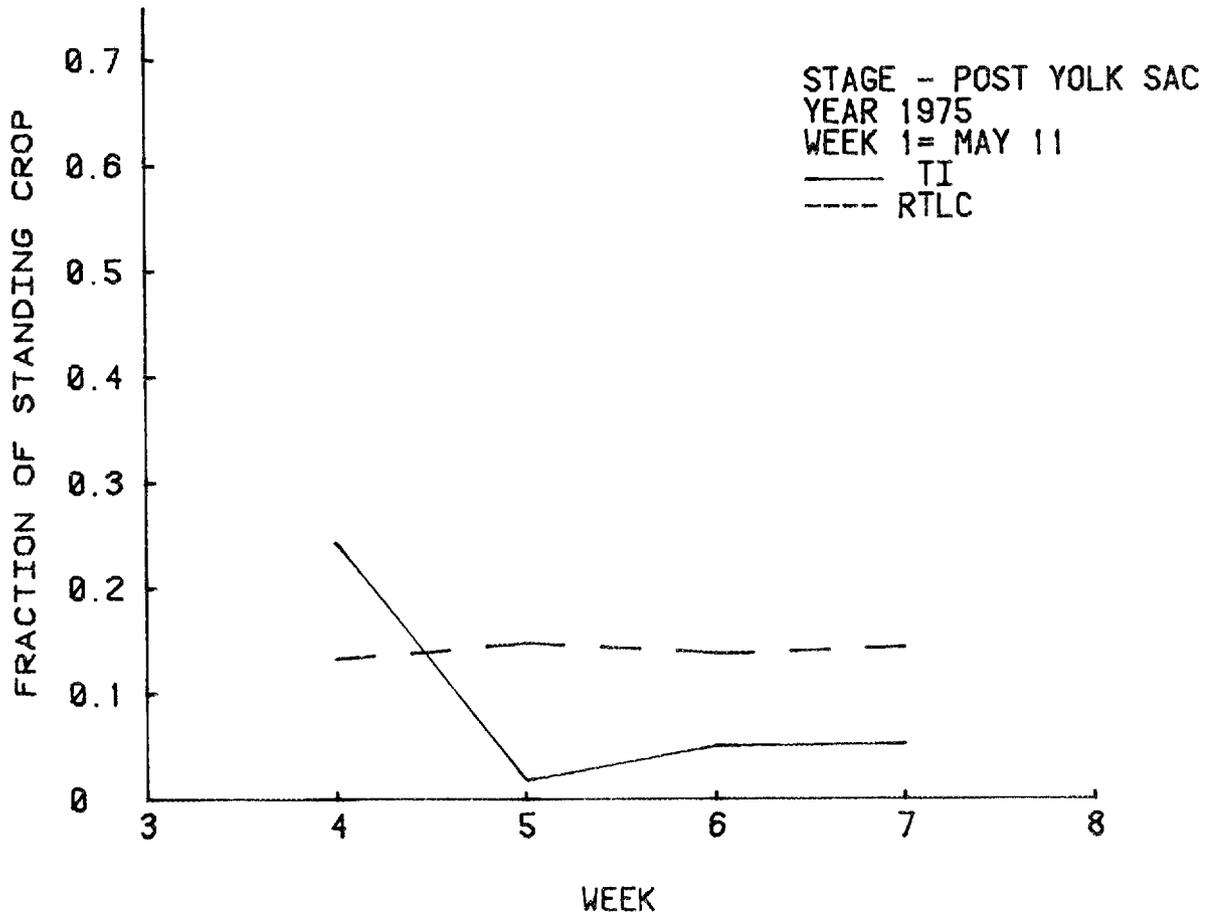


Figure 12. Comparison of observed (TI) and predicted (RTL) temporal changes in fraction standing crop ( $FSC_{i,j}$ ) of pysl during the weeks of relatively high abundance in 1975 in Region 7.

For each of the three power plant regions, we compared the observed (TI) and predicted (RTL) values of  $FSC_{i,j}$  for each weekly period presented in Figures 1-12, and we applied the two criteria presented above to determine agreement or disagreement between the observed and predicted patterns of movement. We found that out of the 39 weekly comparisons (13 weeks for each of the three regions), there were 12 cases of agreement and 27 cases of disagreement. In other words, the RTL had a success rate of 31%. A more detailed discussion follows.

a. YSL-1974. (1) Figure 1 (Region 3 - Bowline Point) indicates that during Weeks 4 and 5 (these two weeks contributed approximately 60% of the total standing crop; see Table 10), the RTL predicted an increase in the fraction standing crop from 0.109 to 0.149, whereas TI indicated a marked decline (0.396 to 0.074). (2) Figure 2 (Region 4 - Indian Point) indicates that during Weeks 6 and 7, the RTL predicted a decrease in the fraction standing crop from 0.174 to 0.085, whereas TI showed a marked increase from 0.018 to 0.371. However, during Weeks 4 and 5, the weeks of greatest abundance, the two curves agree rather well. (3) Figure 3 (Region 7 - Roseton) indicates a complete lack of agreement between the patterns of movement predicted by the RTL and the patterns of movement indicated to have actually occurred (TI) during Weeks 4 and 6. However, during Week 5 there is fair agreement.

b. PYSL-1974. There is very poor agreement in the observed and predicted patterns of movement in Region 3 (Figure 4). For Region 4 (Figure 5), there is good agreement during weeks 7 and 8, but poor agreement during Weeks 5 and 6. For Region 7 (Figure 6), the agreement is poor during Weeks 6 and 8 and good during Weeks 5 and 7.

c. YSL and PYSL-1975. A complete lack of agreement in patterns of movement is apparent for ysl in Region 7 in 1975 and for pysl in Regions 3 and 4 in 1975 (Figures 9, 10, and 11). There was fairly good agreement for ysl in Region 3 (Figure 7). However, for ysl in Region 4 (Figure 8), the RTL predicted a decline in fraction standing crop from 0.266 to 0.200 during Weeks 4 and 5, the weeks of greatest abundance, while TI observed an increase from 0.208 to 0.505. In addition, for pysl in Region 7 during Week 4 (Figure 12), the week of greatest abundance (see Table 11), the RTL predicted a slight increase in the fraction standing crop (0.133 to 0.147), whereas the actual field data indicated a drastic decline (0.243 to 0.018).

#### G. Summary

The reasons for the lack of agreement between the RTL and the TI field data with respect to the longitudinal spatial distributions of ysl and pysl in 1974 and 1975 may include the following:

(1) Possibly inaccurate estimates from the extrapolation technique, which were used to determine net non-tidal flows (an input parameter to the RTL hydrodynamic equations) for freshwater flows less than 10,000 cfs (Tr. 9595-7; Tr. 9607-13), may have resulted in inaccurate determinations of tidal flows.

(2) The ysl and pysl are treated as passive particles in solution, that do not have the ability to move under their own power in the longitudinal direction (Tr. 9626-51).

(3) The utilities' consultant adopted the following three conventions: (a) use of single values for all model segments for the fraction of eggs in the upper layer and lower layer, when, in fact, field data indicated substantial variability from region to region (Tr. 9939-44); (b) use of a single value for all model segments for the migration preference of ysl, when, in fact, field data indicated substantial variability from region to region (Tr. 9939-44); and (c) use of a single value for all model segments for the migration preference of pysl, when, in fact, field data indicated substantial variability from region to region (Tr. 9939-44).

Items 3(a), (b), and (c) determine the fractions of eggs, ysl and pysl susceptible to the different upper-layer and lower-layer tidal flows. Therefore, using the same values over the entire river length may have caused, in part, the inaccurate RTLC predictions of ysl and pysl longitudinal spatial distributions.

10. COMPARISON OF  $M_E$  PREDICTIONS BY THE RTLC AND ETM

In Section 9 a method was developed to predict the effect that differences between the observed (TI) spatial distributions and the spatial distributions predicted by the RTLC have on the prediction of power plant impact. Since the Empirical Transport Model (ETM) uses the observed (TI) spatial distributions of  $ysl$  and  $pysl$  in its  $M_E$  predictions, the availability of power plant conditional mortality rates for the  $ysl$  and  $pysl$  stages generated by the ETM and RTLC under identical plant operating conditions (i.e.,  $f$ -factors and power plant intake flows identical to those used to generate the  $M_E$  values in Table 3-VIII-1 of UT-3) and identical  $ysl$  and  $pysl$  stage durations afforded us the opportunity to test the validity of the approach used in Section 9.

We first calculated  $P_j$  values for the  $ysl$  and  $pysl$  longitudinal spatial distributions input to the ETM. Values for % Differences between the  $P_j$  and  $P$  values of the ETM and RTLC were then calculated for each life stage for both 1974 and 1975. These % Differences were then compared to the corresponding % Differences calculated for the conditional mortality rates predicted by the RTLC and ETM for each life stage and year. Since any differences between the conditional mortality rates predicted by the RTLC and ETM should be principally due to differences between the two models in the longitudinal spatial distributions of the  $ysl$  and  $pysl$ , the two sets of % Difference values should be fairly close, if the methodology of Section 9 is valid.

Tables 14 and 15 present the results of this analysis. The spatial distributions input to the ETM are identical to the TI-based distributions analyzed in Section 9 of this testimony. The differences in the  $P_j$  ( $P_k$ ) values between Tables 12 and 13 and Tables 14 and 15 are the result of the power plants withdrawing water in more than one TI region in the ETM computational scheme (Exhibit EPA-200). Table 16 specifies the regions of water withdrawal and the fractions of water withdrawn from each TI region. This modification necessitated a revision to Eqs. (1) and (2) for  $P_j$  in Section 9.  $P_j$  was defined in Eq. (2) as an index of impact for Region  $j$ , whereas what is needed here is an index of impact for a power plant, denoted by the subscript  $k$ . The expression for  $P_k$  is:

$$P_k = \sum_i \left[ \sum_j FSC_{i,j} W_i Q_{i,k} f_{j,k} \right] , \quad (5)$$

where  $FSC_{i,j}$  and  $W_i$  were previously defined (see Section 9. F of this testimony), and where  $Q_{i,k}$  is the intake flow in Week  $i$  at power plant  $k$ , and  $f_{j,k}$  is the fraction of intake water that power plant  $k$  withdraws from TI Region  $j$ .

Table 14. Comparison of RTLC and ETM with respect to indices of impact and  $M_E$  values for yolk-sac larvae and post yolk-sac larvae for 1974

Life stage	Plant	RTLC <sup>a</sup> $P_j$	ETM <sup>b</sup> $P_k$	% Difference <sup>c</sup>
ysl	Bowline Point	0.0753	0.0487	+ 54.6%
	Indian Point	0.2939	0.1357	+ 116.6%
	Roseton	0.0419	0.2230	- 81.2%
	Total <sup>d</sup>	0.4111	0.4074	+ 0.9%
pysl	Bowline Point	0.0794	0.1119	- 29%
	Indian Point	0.2358	0.2487	- 5.2%
	Roseton	0.0623	0.1234	- 49.5%
	Total <sup>d</sup>	0.3775	0.4840	- 22.0%

COMPARISON OF  $M_E$  VALUES

Life stage	$M_E^e$		% Difference <sup>f</sup>
	RTLC	ETM	
ysl	0.0091	0.0084	+ 8.3%
pysl	0.0141	0.0180	- 21.7%

<sup>a</sup>Values from Table 12.

$$P_k = \sum_i \left[ \sum_j FSC_{i,j} W_i Q_{i,k} f_{j,k} \right]. \text{ See Eq. (5).}$$

$$\% \text{ Difference} = \frac{P_j \text{ (RTLC)} - P_k \text{ (ETM)}}{P_k \text{ (ETM)}} \times 100.$$

$$^d \text{Total} = P = \sum_j P_j \text{ for RTLC and } P = \sum_k P_k \text{ for ETM.}$$

<sup>e</sup> $M_E$  for all three plants.

$$^f \% \text{ Difference} = \frac{M_E \text{ (RTLC)} - M_E \text{ (ETM)}}{M_E \text{ (ETM)}} \times 100.$$

Table 15. Comparison of RTLC and ETM with respect to indices of impact and  $M_E$  values for yolk-sac larvae and post yolk-sac larvae for 1975

Life stage	Plant	RTLC <sup>a</sup> $P_j$	ETM <sup>b</sup> $P_k$	% Difference <sup>c</sup>
ysl	Bowline Point	0.0437	0.1001	- 60.0%
	Indian Point	0.3416	0.2463	+ 38.7%
	Roseton	0.0690	0.0833	- 17.2%
	Total <sup>d</sup>	0.4543	0.4297	+ 5.7%
pysl	Bowline Point	0.0668	0.1554	- 57.0%
	Indian Point	0.2839	0.3418	- 16.9%
	Roseton	0.1019	0.0948	- 7.5%
	Total <sup>d</sup>	0.4526	0.5920	- 23.5%

COMPARISON OF  $M_E$  VALUES

Life stage	$M_E^e$		% Difference <sup>f</sup>
	RTLC	ETM	
ysl	0.0062	0.0068	- 8.8%
pysl	0.0429	0.0630	- 31.9%

<sup>a</sup>Values from Table 12.

$$bP_k = \sum_i \left[ \sum_k FSC_{i,j} W_i Q_{i,k} f_{j,k} \right]. \text{ See Eq. (5).}$$

$$c\% \text{ Difference} = \frac{P_j \text{ (RTLC)} - P_k \text{ (ETM)}}{P_k \text{ (ETM)}} \times 100.$$

$$d\text{Total} = P = \sum_j P_j \text{ for RTLC and } P = \sum_k P_k \text{ for ETM.}$$

<sup>e</sup> $M_E$  for all three plants.

$$f\% \text{ Difference} = \frac{M_E \text{ (RTLC)} - M_E \text{ (ETM)}}{M_E \text{ (ETM)}} \times 100.$$

Table 16. Fraction of intake flow withdrawn in TI river regions by Bowline Point, Indian Point, and Roseton in the ETM computational scheme

Plant, k	j =	$f_{j,k}^a$					
		2	3	4	5	6	7
Bowline Point		0.271	0.358	0.371			
Indian Point			0.298	0.562	0.140		
Roseton						0.273	0.727

<sup>a</sup><sub>j</sub> = number of TI river region; see Table 5.

## Results

The % Differences calculated for the ysl stage using the RTLC and ETM 1974 and 1975 P values indicate that the RTLC and ETM should predict very similar  $M_E$  values (% Difference values of +0.9% in 1974 and +5.7% in 1975; see Tables 14 and 15). Comparison of the % Differences calculated for the ysl  $M_E$  values predicted by the two models support this prediction (% Difference values of + 8.3% in 1974 and - 8.8% in 1975). It should be noted, again, that the good agreement between the two models in predicting total power plant impact with respect to the ysl stage in 1974 is the fortuitous result of offsetting inaccuracies in the RTLC prediction of ysl longitudinal spatial distribution, as reflected by the % Differences of the individual plant values for  $P_j$  in Table 12 (see Section 9 for a detailed discussion).

The % Differences for the pysl stage total P values indicate that the ETM - generated index of impact is 22.0% greater than the corresponding RTLC - generated index of impact in 1974 (Table 14) and 23.5% greater in 1975 (Table 15). The % Differences calculated for the RTLC and ETM generated  $M_E$  values show the same pattern (% Difference = -21.7% in 1974 and -31.9% in 1975), indicating that the index of impact and  $M_E$  are positively related within life stages, as would be expected.

Based on the results in this section, the validity of utilizing  $P_j$  values as done in Section 9 to compare the two sets of longitudinal spatial distributions and their effect on power plant impact predictions has been demonstrated.

In addition, the results of Sections 9 and 10 indicate quite strongly that differences in predictions of impact between the RTLC and ETM for ysl and pysl are due primarily to the generation of longitudinal spatial distributions by the RTLC which differ from the observed distributions. Since the observed distributions are considered the correct distributions, the ETM gives a more valid prediction than the RTLC of  $M_E$  for ysl and pysl.

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