A Selective Analysis of Power Plant Operation on the Hudson River with Emphasis on the Bowline Point Generating Station

Volume 2

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ENERGY DIVISION

A SELECTIVE ANALYSIS OF POWER PLANT OPERATION
ON THE HUDSON RIVER WITH EMPHASIS
ON THE BOWLINE POINT GENERATING STATION

Volume 2

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ABSTRACT

A comprehensive study of the effects of power plant operation on the Hudson River was conducted for the U.S. Army. The study included thermal, biological, and air quality effects of existing and planned electrical generating stations.

The section addressing thermal impacts presents a comprehensive mathematical modeling and computer simulation study of the effects of heat rejection from the plants. The overall study consisted of three major parts: (1) near-field analysis, (2) far-field analysis, and (3) zone-matched near-field/far-field analysis. Near-field analyses were completed for Roseton, Danskammer, and Bowline Point Generating Stations, and near-field dilution ratios range from a low of about 2 for Bowline Point and 3 for Roseton to a maximum of 6 for both plants.

The far-field analysis included a critical review of existing studies and a parametric review of operating plants. The maximum thermal load case, based on hypothetical 1974 river conditions, gives the daily maximum cross-section-averaged and 2-mile-segment-averaged water temperatures as 83.80°F in the vicinity of the Indian Point Station and 83.25°F in the vicinity of the Bowline Station. This maximum case will be significantly modified if cooling towers are used at certain units. A full analysis and discussion of these cases is presented.

The Roseton and Danskammer plants give rise to maximum seasonal ground-level concentrations of about 40 $\mu\text{g}/\text{m}^3$, while the Bowline and Lovett plants are responsible for a maximum value which is about one-tenth of this concentration.

Section 5 focuses on the Hudson River striped bass population and is divided into the following eight subsections: (1) distribution of striped bass eggs, larvae, and juveniles in the Hudson River; (2) entrainment mortality factor (f_c); (3) intake f factor (f_I); (4) impingement; (5) effects of discharges; (6) compensation; (7) model estimates of percent reduction; and (8) Hudson River striped bass stock.

ORNL estimates of f_c range from 0.50 to 0.73 for eggs, 0.57 to 0.86 for yolk-sac larvae, 0.00 to 0.82 for post-yolk-sac larvae, and 0.18 to 0.77 for entrainable juveniles. ORNL estimates of f_I range from 0.92 to 12.4 for eggs, 0.34 to 1.26 for yolk-sac larvae, 0.05 to 1.02 for post-yolk-sac larvae, and 1.9 to 16.1 for entrainable juveniles. Due to a number of sampling problems, ORNL has little confidence in either Consolidated Edison or ORNL estimates of f_I . Forecasts of the annual number of striped bass impinged for various power plant configurations indicate that the number impinged would be reduced to approximately 30% of the number impinged with the reference configuration (i.e., once-through cooling at Bowline, Indian Point, and Roseton) if closed-cycle cooling were installed at each of these three power plants. Installing closed-cycle cooling at Bowline, as compared to Indian Point, would be more effective in reducing the number of striped bass impinged annually.

Oak Ridge National Laboratory readily endorses the concept of compensation and the likelihood that some compensation is occurring and will continue to occur. The primary issue in controversy is the amount of compensatory capacity which a priori should be assumed to exist in the population and, therefore, the extent to which the effects of increased mortality due to power plants will be offset. The two lines of evidence for compensation in the Hudson River striped bass population presented by Texas Instruments (TI) are evaluated. A summary of ORNL's critique and sensitivity analysis of the compensation function used in the utilities, striped bass models is presented.

Estimates of percent reduction due to power plant operation are presented based on runs of the utilities' combined one-dimensional transport model and life-cycle model. Estimates of percent reduction are very sensitive to the strength and form of the compensation function. For the full range of values used for f factors and the preferred form of the compensation function, the ratio of maximum to minimum percent reduction is as much as a factor of 3.0. Percent reduction varies approximately 1:1 with power plant withdrawal rate, although there are variations in this relationship due to spatial effects. The risk of irreversible damage to the Hudson River striped bass population because of exploitation by the power plants and fishery combined is considered to be small.

Analyses by ORNL and TI support the position that the Hudson River stock contributes to the striped bass population found along the Atlantic coast at least as far north as Boston, Massachusetts, and as far south as somewhere along the coast of New Jersey. In the absence of a detailed report from TI documenting the additional statistical techniques to reduce bias, and in the absence of an independent analysis of the raw data, it seems reasonable to use the full range of TI's original and modified estimates of percent contribution of 15 to 32% to the NRC Inner Zone, 0 to 19% to the NRC Outer Zone, and 7 to 23% to the coastal fishery as "working ranges."

SUMMARY AND CONCLUSIONS

S.1 Thermal Effects

The conclusions related to the thermal effects can be stated in three parts based on the three analyses which were considered in the assessment of the potential thermal impact of power plant operations on the Hudson River.

S.1.1 Near-field analysis

The following conclusions are based on the results of the near-field analysis of the discharge conditions from Roseton Generating Station, Danskammer Point Generating Station, and Bowline Point Generating Station (Sect. 3.3):

1. The cooling of the thermal plumes in the near-field zones will depend on the mixing of the heated discharge water with the local ambient water according to the characteristics of the discharge diffusers. Dilution ratios within the general range of 2 to 6 can be expected.

2. The actual values of the dilution factors will depend on the spatially and temporally varying cross-flow conditions, which are dominated by the periodic tidal conditions. The lower limit of the dilution factor range for the submerged discharges will correspond to the high cross-flow conditions during maximum ebb and flood tidal stages due to the particular parallel orientations of the diffusers relative to the flow in the estuary.

3. The thermal behavior of the discharge plumes will be strongly dependent on the reentrainment and recirculation phenomena controlled by the tidal flow conditions in the far-field zone.

S.1.2 Far-field analysis

The analysis of the far-field thermal impact of multi-power-plant operation on the complete estuary (Sect. 3.4) was based on the reasonably typical natural river conditions during April 1 through September 30 in 1974. The following conclusions are based on the results of the far-field analysis:

1. The far-field thermal impact of power plant operations during the period April through September 1974 was extremely low. Although 1974 was a typical year for the natural conditions in the estuary and the region, the thermal load on the river was extremely low in comparison to the rated output capacity of the existing power plants. Hence, the field-measured data about the thermal conditions in the river during the period April through September 1974 are definitely not indicative of the potential thermal impact of power plant operations on the Hudson River.

2. Based on hypothetical 1974 river conditions, for case 3 (proposed maximum thermal load - Greene County power plant with closed-cycle plant cooling system, all other plants with once-through plant cooling systems) (see Table 3.4.13), the daily-averaged, cross-section-averaged, and 2-mile-segment-averaged water temperature conditions in the estuary will not exceed the limit of elevated temperature level 4°F above "the temperature that existed before the addition of the heat of artificial origin" (clean river conditions) as stated by the applicable State and Federal standards (see Sect. 3.1).

3. Based on hypothetical 1974 river conditions, for case 3 (proposed maximum thermal load), the daily-averaged, cross-section-averaged, and 2-mile-segment-averaged water temperature conditions will exceed the limit of "a maximum of 83°F " over areas exceeding "50 percent of the cross-sectional area of the estuary" as stated by the applicable State and Federal standards (see Sect. 3.1).

4. Based on hypothetical 1974 river conditions, for case 3 (proposed maximum thermal load), the daily-maximum cross-section-averaged and 2-mile-segment-averaged water temperatures will be 83.80°F in the vicinity of the Indian Point power plant and 83.25°F in the vicinity of the Bowline power plant during late July and August. The daily-maximum cross-section-averaged and 2-mile-segment-averaged water temperatures will not exceed 83°F at any other location along the estuary. Hence, the limit of "a maximum of 83°F " over areas exceeding "50 percent of the cross-sectional area of the estuary" as stated by the applicable State and Federal standards (see Sect. 3.1) will only be violated in the 6-mile section of the river where the Indian Point and Bowline plants are located.

5. Based on hypothetical 1974 river conditions, for case 7 (proposed maximum thermal load except Bowline power plant with closed-cycle plant cooling system) (see Table 3.4.13), the daily-maximum cross-section-averaged and 2-mile-segment-averaged water temperatures will be 83.42°F in the vicinity of the Indian Point power plant and 82.63°F in the vicinity of the Bowline power plant. Hence, the thermal conditions in the river will again exceed the limit of "a maximum of 83°F " over areas exceeding "50 percent of the cross-sectional area of the estuary" as stated by the applicable State and Federal standards (see Sect. 3.1). Hence, the operation of the Bowline power plant with closed-cycle plant cooling system will not be a feasible alternative for the reduction of the far-field thermal impact on the Hudson River.

6. Based on hypothetical 1974 river conditions, for case 8 (proposed maximum thermal load except Indian Point power plant with closed-cycle plant cooling system) (see Table 3.4.13), the daily-averaged, cross-section-averaged, and 2-mile-segment-averaged water temperatures will be 80.70°F in the vicinity of the Indian Point power plant and 81.48°F in the vicinity of the Bowline power plant; and the daily-maximum cross-section-averaged and 2-mile-segment-averaged water temperatures will be 81.66°F in the vicinity of the Indian Point power plant and 82.00°F in the vicinity of the Bowline power plant. Therefore,

the temperature conditions will be approximately 2°F lower than the case with once-through plant cooling system and they will definitely comply with the limit of "a maximum of 83°F" over areas exceeding "50 percent of the cross-sectional area of the estuary" as stated by the applicable State and Federal standards (see Sect. 3.1). Hence, the operation of the Indian Point power plant with closed-cycle plant cooling system will be a feasible alternative for the reduction of the thermal impact on the Hudson River.

7. Based on hypothetical 1974 river conditions, operation of Greene County power plant with once-through plant cooling system will increase the cross-section-averaged and 2-mile-segment-averaged water temperatures by less than 0.1°F in the vicinity of the Indian Point power plant and 0.05°F in the vicinity of the Bowline power plant. Hence, the operation of the Greene County power plant with once-through plant cooling system will not have any critical effect on the far-field thermal impact conditions on the Hudson River.

S.1.3 Zone-matched near-field and far-field (complete) analysis

The zone-matched near-field and far-field analysis (Sect. 3.5) was applied to the simulation of the detailed temperature distributions in the vicinities of the Bowline and Indian Point power plants based on hypothetical August 4, 1974, river conditions, when the far-field thermal impact on the estuary becomes critical for case 3 (proposed maximum thermal load plant operational conditions) (see Table 3.4.13). The following conclusions are based on the results of the zone-matched near-field and far-field analysis:

1. The critical thermal conditions in the vicinity of the Bowline power plant will generally occur during the afternoon and evening between 1300 and 2200 hr.

The operation of the Bowline power plant will violate the applicable New York State thermal standards (see Sect. 3.1) based on the occurrence of the following thermal conditions: (a) Surface temperature exceeding 91°F (90°F limit) will occur in the vicinity of the plant. Hence item i will be violated. (b) Water temperatures of 84°F (83°F limit) will occur over one-third of the surface as measured from water edge to water edge. Hence, item ii will be violated. (c) Water temperatures of 84°F (83°F limit) will occur over 50% of the cross-sectional area and/or volume of the flow of the estuary. Hence, item ii will be violated.

The operation of the Bowline power plant will violate the criterion recommended by the Environmental Protection Agency (see Sect. 3.1), which limits the extent of the 83°F temperature to 1000 ft from the discharge, based on the occurrence of the following thermal conditions: (d) Water temperatures of 87°F (83°F limit) will occur at distances more than 3000 ft from the discharge. (e) Water temperatures of 84°F (83°F limit) will occur at distances more than 6000 ft from the discharge.

2. The critical thermal conditions in the vicinity of the Indian Point power plant will generally occur during the afternoon and evening between 1300 and 2200 hr.

The operation of the Indian Point power plant will violate the applicable New York State thermal standards (see Sect. 3.1) based on the occurrence of the following thermal conditions: (a) Surface temperature exceeding 94°F (90°F limit) will occur in the vicinity of the plant. Hence item i will be violated. (b) Water temperatures of 84°F (83°F limit) will occur over the total surface area as measured from water edge to water edge. Hence, item ii will be violated. (c) Water temperatures of 84°F (83°F limit) will occur over 100% of the cross-sectional area and/or volume of the flow of the estuary. Hence, item ii will be violated.

The operation of the Indian Point power plant will violate the criterion recommended by the Environmental Protection Agency (see Sect. 3.1), which limits the extent of the 83°F temperature to 1000 ft from the discharge, based on the occurrence of the following thermal conditions: (d) Water temperatures of 87°F will occur at distances more than 2500 ft from the discharge. (e) Water temperatures of 84°F will occur at distances more than 8000 ft from the discharge.

S.1.4 Summary: conclusions and recommendations

The results of the overall thermal impact analysis can be summarized by the following conclusions:

1. The thermal conditions in the Hudson River for typical river flows and climatological conditions in the region and for the proposed maximum thermal load plant operational conditions (Greene County power plant with closed-cycle plant cooling system, all other plants with once-through plant cooling systems) with all power plants at full rated output power will violate the applicable New York State thermal standards and the thermal criterion recommended by the Environmental Protection Agency at certain days during late July and August.

2. The critical thermal conditions in the Hudson River which violate the applicable New York State thermal standards and the thermal criterion recommended by the Environmental Protection Agency will occur in the vicinities of the Indian Point and Bowline power plants during the afternoon and evening hours on various days in July and August.

3. The level of the violations of the applicable New York State thermal standards and the thermal criterion recommended by the Environmental Protection Agency will not be excessive for typical river flow conditions in the Hudson River.

4. The level of the violations of the applicable New York State thermal standards and the thermal criterion recommended by the

Environmental Protection Agency will increase with decreasing freshwater flow conditions in the Hudson River.

The results of the overall thermal impact analysis lead to the following recommendations (strictly based on thermal impact considerations):

1. Essential alternative: Indian Point power plant operating with closed-cycle plant cooling system.
2. Optional alternative: Greene County power plant operating with once-through plant cooling system.

The proposed two alternatives will reduce the thermal impact of power plant operations on the Hudson River by approximately 2°F at the locations of Indian Point and Bowline power plants for typical river flow and climatological conditions.

3. Reduced power output alternative: with essential alternative 1 and optional alternative 2 as applicable, the critical thermal conditions which could result from reduced freshwater flow conditions for short durations can be avoided by reducing power output at selected power plants along the estuary based on careful considerations of the overall thermal impact on the Hudson River.

S.1 Air Quality

It has been shown (Sect. 4.3.2) that the Roseton and Danskammer plants are responsible for much higher sulfur dioxide concentrations in their vicinity than the Bowline and Lovett plants are. The Roseton and Danskammer plants give rise to maximum seasonal ground-level concentrations of about 40 $\mu\text{g}/\text{m}^3$, while the Bowline and Lovett plants are responsible for a maximum value which is about one-tenth of this. When the combined effects of all four plants are considered (Sect. 4.3.3), the maximum seasonal ground-level concentration is still expected to be on the order of 40 $\mu\text{g}/\text{m}^3$.

Although cooling-tower-smokestack plume interactions will likely give rise to some acidic water droplet deposition, it is felt that this will not be a problem (Sect. 4.3.5). This conclusion is based on the fact that, over many years, the operation of wet cooling towers in proximity to fossil-fueled plant smokestacks has not proved to be a source of adverse effects. Furthermore, the lower sulfur content of the Bowline plant's fuel would further mitigate any adverse effects at that location.

The natural-draft cooling towers at Bowline and Roseton appear to pose no fogging problem at either site. As shown in Sect. 4.3.4, no incidence of ground fog due to tower operation was found, a result consistent with the observation that natural-draft cooling tower plumes rarely touch the ground.

Both the Bowline and Roseton sites showed a peak annual average aerosol concentration of about $0.2 \mu\text{g}/\text{m}^3$. This is substantially below the $10 \mu\text{g}/\text{m}^3$ found by Moser¹ to cause no detrimental effects in sensitive vegetation. Maximum salinity occurs in August, and the ratio of the peak salinity to the annual average is about 3. This would raise the aerosol level to about $0.6 \mu\text{g}/\text{m}^3$, still an order of magnitude smaller than the figure quoted by Moser.¹

Reference for Section S.2

1. B. G. Moser, "Airborne Sea Salt: Techniques for Experimentation and Effects on Vegetation," in *Cooling Tower Environment - 1974*, ERDA Symposium Series, CONF-740302, 1975, pp. 353-369.

S.3 Effects on the Hudson River Striped Bass Population

With respect to the assessment of the potential multiplant impact on the Hudson River striped bass population (Sect. 5), ORNL has reached the following conclusions.

S.3.1 Entrainment mortality factor (f_C) (Sect. 5.3)

Estimates of the entrainment mortality factor (f_C), defined as the probability that a live organism will be killed due to the entrainment process, depend on the life stage, the power plant, and the method of calculation. Consolidated Edison's estimates range from 0.49 to 0.78 for eggs, 0.57 to 1.00 for yolk-sac larvae, 0.00 to 0.73 for post-yolk-sac larvae, and 0.00 to 0.69 for entrainable juveniles (Table 5.3.11). ORNL estimates of short- and intermediate-term mortality range from 0.50 to 0.73 for eggs, 0.57 to 0.86 for yolk-sac larvae, 0.00 to 0.82 for post-yolk-sac larvae, and 0.18 to 0.77 for entrainable juveniles (Tables 5.3.12-5.3.15). Both Consolidated Edison and ORNL "best" estimates were used in model runs.

S.3.2 Intake f factor (f_I) (Sect. 5.4)

Estimates of the intake factor (f_I), which is the ratio of the concentration of entrainable ichthyoplankton in the intake water to the concentration in the river, also depend on the life stage, the power plant, and the method of calculation. Consolidated Edison's estimates, based on 1974 and 1975 data, range from 0.0 to 6.0 for eggs, 0.09 to 1.08 for yolk-sac larvae, 0.04 to 2.08 for post-yolk-sac larvae, and 0.0 to 1.0 for entrainable juveniles. ORNL estimates, based on data that became available after the IP3 FES, range from 0.92 to 12.4 for eggs, 0.34 to 1.26 for yolk-sac larvae, 0.05 to 1.02 for post-yolk-sac larvae, and

1.9 to 16.1 for entrainable juveniles (Tables 5.4.7, 5.4.11, 5.4.12, 5.4.14, and 5.4.15). Due to a number of sampling problems, ORNL has little confidence in the accuracy of either the Consolidated Edison or the ORNL estimates (whether those made in the IP3 FES or those indicated above). Consequently, in model simulations, ORNL has continued (as in the IP3 FES) to use the values of 0.5 and 1.0 for f_I for all four entrainable life stages at all power plants.

S.3.3 Striped bass impingement (Sect. 5.5)

1. Collection efficiency of impinged striped bass at Indian Point Unit 2 with the air curtain on was estimated by Texas Instruments to be 12% in 1974 and 17% in 1975. Estimates at Indian Point Unit 2 without the air curtain, Indian Point Unit 3, and the other power plants are not available. ORNL assumed a collection efficiency of 50% at all plants in calculating the annual number of striped bass expected to be impinged for various power plant configurations (Sect. 5.5.1.2).

2. Latent survival of impinged striped bass appears to be low. ORNL assumed a survival of 0% in calculating the annual number of striped bass expected to be impinged for various power plant configurations (Sect. 5.5.1.3).

3. For Bowline, Lovett, and Indian Point, collection rates tend to be high from December through April and low from May through October; primarily young of the year are impinged. For Roseton, Danskammer, and Albany, collection rates tend to be high from June through October or November and low from January through April; primarily yearling striped bass may be impinged (Sect. 5.5.1.4).

4. Forecasts of the annual number of striped bass impinged for various power plant configurations indicate that the number impinged would be reduced to approximately 30% of the reference configuration (i.e., once-through cooling at Bowline, Indian Point, and Roseton) if closed-cycle cooling were installed at each of these three power plants. Installing closed-cycle cooling at Bowline would be more effective in reducing the number of striped bass impinged annually than installing closed-cycle cooling at either Indian Point or Roseton (Sect. 5.5.2).

S.3.4 Effects of discharges (Sect. 5.6)

1. The temperature of the Hudson River in the immediate vicinity of the power plants may be increased under certain conditions to levels detrimental to young-of-the-year striped bass. Exposure temperature, duration of exposure, and size, mobility, and thermal history of each life stage will be important in determining the effects of thermal stress. Excess temperatures may attract striped bass to the intakes during the winter, which could cause additional impingement. Excess temperatures may alter the spawning distribution of striped bass to some extent (Sect. 5.6.1).

2. The dissolved oxygen concentration in the vicinity of Bowline, Roseton, and Indian Point may be reduced to levels detrimental to young-of-the-year striped bass during extreme conditions of low freshwater flow, high river temperatures, and full-power operation of these three plants (Sect. 5.6.2).

3. Chlorination of the once-through cooling systems at Bowline, Roseton, and Indian Point will result in high mortalities of young-of-the-year striped bass passing through the plant during chlorination (Sect. 5.6.3).

Overall, the direct and indirect effects of discharges on the various life stages of young-of-the-year striped bass are expected to be minor in comparison with those from entrainment and impingement.

S.3.5 Compensation (Sect. 5.7)

1. ORNL readily endorses the concept of compensation and the likelihood that some compensation (both natural and through the fishery) is occurring and will continue to occur to some degree. The primary issue in controversy for regulatory agencies, utilities, and society in general is the amount of compensatory capacity which a priori should be assumed to exist in the population and, therefore, the extent to which the effects of increased mortality due to power plants will be offset (Sect. 5.7.6).

2. Texas Instruments presents two lines of evidence for compensation in the Hudson River striped bass population. While there are uncertainties and problems associated with each analysis, the two analyses do suggest that some density-dependent population changes may have occurred during the period 1955-1973. ORNL's position is that the Hudson River striped bass population should be assumed to have the capacity to compensate to some extent for increased mortality such as that imposed by power plants. However, the TI analyses do not remove ORNL's concern for the long-term consequences of a protracted increase in density-independent mortality, such as the cropping imposed by power plants, because the range of cropping rates that could be offset by compensatory responses and the degree of offset are not known (Sect. 5.7.3).

3. ORNL's critique and sensitivity analysis of the compensation function used in the Lawler, Matusky, and Skelly Engineers Hudson River striped bass models indicates that (1) the mathematical formulation is not conceptually sound from a biological point of view, (2) none of the three parameters in the compensation function can be based directly or indirectly on observable data, (3) model estimates of percent reduction are sensitive to the values selected for each of the three parameters, and percent reductions can vary by a factor of 10 depending on that choice, and (4) disabling the left limb of the LMS compensation function results in a function that ORNL believes to be conceptually more sound but that leads to appreciably higher estimates of percent reduction. Model runs were done both with the original LMS function and with the left limb disabled (Sect. 5.7.4).

S.3.6 Model estimates of percent reduction (Sect. 5.8)

1. Estimates of percent reduction due to power plant operation were obtained using the LMS one-dimensional model linked to the LMS life-cycle model. The mean percent reduction for yearlings after one year of plant operation is 6.8% and the mean percent reduction for the adult population after 40 years of plant operation is 18.2% for the 12 runs with the left limb of the compensation function not disabled. ORNL considers the compensation function with the left limb disabled to be conceptually more sound. For the corresponding 12 runs with the left limb disabled, the corresponding two means are 7.9% and 32.9%. Thus disabling the left limb results in appreciably higher estimates of percent reduction (Sect. 5.8.3.1).

2. Estimates of percent reduction are very sensitive to the strength of the compensation function. Percent reduction values reflect a greater relative importance of impingement in the ORNL runs of the LMS 1-D model as compared to the LMS runs of this model (Sect. 5.8.3.2).

3. For the full range of values used for both compensation and the composite f factor, the ratio of maximum to minimum percent reduction of yearlings after one year or of adults after 40 years differs by a factor of 1.5 to 2.0. Considering these two sets of input parameters in combination, this ratio can differ by as much as a factor of 3.0. None of the compensation or f-factor levels used in this sensitivity analysis can be completely discredited; adequate data are simply not available. The effect of uncertainties in these two sets of input parameters is reflected in turn by estimates of percent reduction that can differ by as much as a factor of 2.0 to 3.0. Because of additional uncertainties that were not included in this sensitivity analysis (e.g., impingement rates, the reference population size, transport avoidance factors), the true range of uncertainty is somewhat greater than this (Sect. 5.8.3.3).

4. Percent reduction varies approximately 1:1 with power plant withdrawal rate. Percent reduction values with closed-cycle cooling at Bowline, Roseton, and Indian Point are lower than the values with once-through cooling at these three plants by factors of approximately 4 to 6. There are variations in the strict relationship between percent reduction and withdrawal rate due to spatial effects. It appears that installing cooling towers at Roseton would be less effective in decreasing percent reduction than installing cooling towers at either Bowline or Indian Point (Sect. 5.8.3.4).

5. The emphasis in discussing the results of the LMS 1-D model is on trends, inequalities, and qualitative and semiquantitative properties of the forecasts. ORNL emphasizes that the model is a single-species population model, which appears to simulate the behavior of the striped bass population in a reasonable manner. ORNL considers the model to be sufficiently realistic to a first approximation to serve as part of the basis for making a rational management decision concerning the acceptability or unacceptability of once-through cooling at Bowline, Roseton, and Indian Point and, if unacceptable, the timing of installation of closed-cycle cooling at the three plants (Sect. 5.8.4).

6. It is ORNL's judgment that the risk of irreversible damage to the Hudson River striped bass population due to exploitation by the power plants and fishery combined is considered to be small, even with once-through cooling at Bowline, Roseton, and Indian Point (Sect. 5.8.4).

S.3.7 Hudson River striped bass and Atlantic coastal populations
(Sect. 5.9)

1. ORNL and Texas Instruments analyses both support the position that the Hudson River stock does contribute to the striped bass population along the Atlantic coast, at least as far north as Boston, Massachusetts. The southern boundary of the zone of influence, based on location of recaptures, is still vague, although it is probably somewhere along the coast of New Jersey (Sect. 5.9.1).

2. The issue of the relative contribution of the Hudson River stock to the Atlantic coastal striped bass population figures prominently in reaching a reasoned decision on the need for closed-cycle cooling at Bowline, Roseton, and Indian Point. Thus, given the importance of this issue, the only recent availability of the TI report, and the obvious sensitivity of the estimates to the method of analysis, the following conclusion is appropriate at this time. The TI study does appear to have narrowed the range of uncertainty from the previous range which was approximately 10 to 80%. In addition, the new estimates are closer to 10% than to 80%. However, in the absence of a detailed report from TI documenting the "additional statistical techniques . . . to reduce the bias" and in the absence of an independent analysis of the raw data, it seems reasonable to use the estimates of percent contribution of 15 to 32% to the NRC inner zone, 0 to 19% to the NRC outer zone, and 7 to 23% to the coastal fishery as a "working range" (Sect. 5.9.2).

5. ASSESSMENT OF THE POTENTIAL MULTIPLANT IMPACT ON THE HUDSON RIVER STRIPED BASS POPULATION

5.1 Introduction

Because of the location of the Bowline, Roseton, and Indian Point power generating facilities in the low-salinity zone of the Hudson estuary, operation of these plants with the present once-through cooling systems will adversely influence the fish populations that use the area for spawning and initial periods of growth and development. Recruitment rates and standing crops of several fish species may be lowered in response to the increased mortality caused by entrainment of nonscreenable eggs and larvae and by impingement of screenable young of the year.

Entrainment and impingement data are particularly relevant for assessing which fish species have the greatest potential for being adversely affected by operation of Bowline, Roseton, and Indian Point with once-through cooling. These data from each of these three plants suggest that the six species that merit the greatest consideration are striped bass, white perch, tomcod, alewife, blueback herring, and bay anchovy. Direct effects on freshwater species that commonly occur in the vicinity of these plants are not expected to be severe. Also, direct effects on the Atlantic sturgeon (listed as a rare species) and the shortnose sturgeon (listed as an endangered species) are not expected to be severe, since young of these species are only occasionally impinged and entrained.

The three-month periods when entrainment and impingement at Indian Point are generally highest are given in Table 5.1.1 for each of the six species. The pattern of impact over the year is such that during no month can the impact of plant operation be ignored, although June and July appear to be the worst for entrainment and December, January, and February appear to be the worst for impingement.

Two points of view are available for assessing the relative importance of the fish species in the Hudson River. From the fisheries point of view, the only two species of major importance are striped bass and shad. There is a limited commercial fishery in the Hudson River for blueback herring and white perch; the mean annual catch during the period 1965 through 1970 was 4150 lb of blueback herring and 1650 lb of white perch.¹ The sport fishery for white perch in the Hudson River is casual and not well defined, but it may be appreciable. The alewife that use the Hudson River as a spawning and nursery area contribute an unknown amount to the coastal alewife fishery.² There are no appreciable commercial or sport fisheries for the anchovy or tomcod that use the Hudson River as a spawning and nursery area.

From the fish-community and ecosystem point of view, the dominant species, as determined by seasonal and regional standing crops (in numbers and biomass per hectare), are the six species most commonly entrained and impinged, namely, striped bass, white perch, tomcod, alewife, blueback

Table 5.1.1. Three-month periods when entrainment and impingement at Indian Point tend to be highest for each of the six fish species of greatest concern

Species	Entrainment ^a	Impingement ^b
Striped bass	May-July	December-February
White perch	May-July	December-February
Tomcod	February-April	August-October
Alewife and blueback herring	June-August	September-November
Anchovy	July-September	August-October

^aNew York University Medical Center, Institute of Environmental Medicine, Laboratory for Environmental Studies, *Hudson River Ecosystem Studies, Effects of Entrainment by the Indian Point Power Plant on Hudson River Estuary Biota, Progress Report for 1971 and 1972*, prepared for Consolidated Edison Company of New York, September 1973 (issued March 1974).

^bConsolidated Edison Company of New York, Inc., *Environmental Report, Indian Point Unit No. 3*, Appendix BB.

herring, and anchovy.¹ On both a temporal and a spatial basis, these species occupy different niches. Considered together, these six species constitute the basic functional structure of the complex fish community in the Hudson River estuary.

Oak Ridge National Laboratory's position with respect to the potential impact of Bowline, Roseton, and Indian Point (operating with once-through cooling) on fish populations in the Hudson River estuary is as follows:

1. The species of greatest concern are striped bass, white perch, tomcod, alewife, blueback herring, and anchovy.
2. The entrainment and impingement impact of Bowline, Lovett, Indian Point, Roseton, and Danskammer all operating with once-through cooling will probably reduce the standing crops of young of the year and adults of each of these species.
3. The reductions are not expected to be irreversible.
4. The quality and quantity of data now available for predicting the effect of power plant operation on fish populations are relatively good for striped bass, white perch, and tomcod.

Section 5 of this report focuses on the Hudson River striped bass population, exclusive of the other five species mentioned above, for several reasons. First, the striped bass is of economic importance to

the commercial fishery and of economic and social importance to the sport fishery. Second, because of the special interests of intervenors involved in various licensing procedures for power plants along the Hudson River, there have been pressures on utilities, consultants, and regulatory agencies to assess the impact of power plant operation on the striped bass population in detail. Third, because of the first two reasons, there is a longer-term and more complete data base available for striped bass than for any other species in the Hudson River. Finally, to some extent, a detailed assessment of this population can serve as a surrogate or an indication of the potential impact on other fish populations in the Hudson River.

The remaining subsections of Sect. 5 cover the following topics: 5.2, distribution of striped bass eggs, larvae, and juveniles in the Hudson River; 5.3, entrainment mortality factor (f_c); 5.4, intake factor (f_I); 5.5, impingement of striped bass; 5.6, effects of discharges; 5.7, compensation; 5.8, model estimates of percent reduction; and 5.9, Hudson River striped bass stock.

Throughout Sect. 5, the following references will be given in the line of text as abbreviations, followed by citations to pages, sections, appendices, figures, or tables:

- IP3 ER Environmental Report (and 12 supplements) for Indian Point Unit 3 (ref. 3)
- IP3 FES Final Environmental Statement for Indian Point Unit 3 (ref. 4)
- IP3 DES Draft Environmental Statement for Indian Point Unit 3 (ref. 5)
- IP2 FES Final Environmental Statement for Indian Point Unit 2 (ref. 6)

References for Section 5.1

1. Texas Instruments, Inc., *Hudson River Ecological Study, Second Annual Report*, prepared for Consolidated Edison Company of New York, Inc., July 1974.
2. S. B. Saila and S. D. Pratt, "Mid-Atlantic Bight Fisheries," chap. 6 in *Coastal and Offshore Environmental Inventory*, Marine Publication Series No. 2, University of Rhode Island, Kingston, R.I., 1973.
3. Consolidated Edison Company of New York, Inc., *Environmental Report, Indian Point Unit No. 3*, and Appendices, vols. 1 and 2 issued June 14, 1971, including Suppl. No. 1, December 8, 1971; Suppl. No. 2, September 11, 1972; Suppl. No. 3, November 8, 1972; Suppl. No. 4, February 7, 1973; Suppl. No. 5, March 15 and 30, 1973; Suppl. No. 6, April 6, 1973; Suppl. No. 7, April 18, 1973; Suppl. No. 8, April 30, 1973; Suppl. No. 9, September 12, 1973; Suppl. No. 10, October 29, 1973; Suppl. No. 11, December 26, 1974; Suppl. No. 12, March 29, 1974.
4. U.S. Nuclear Regulatory Commission, *Final Environmental Statement Related to Operation of Indian Point Nuclear Generating Plant, Unit No. 3*, NUREG-75/002, Docket No. 50-286, vols. I and II, February 1975.
5. U.S. Atomic Energy Commission, *Draft Environmental Statement Related to Operation of Indian Point Nuclear Generating Plant, Unit No. 3*, Docket No. 50-286, October 1973.
6. U.S. Atomic Energy Commission, *Final Environmental Statement Related to Operation of Indian Point Nuclear Generating Plant, Unit No. 2*, Docket No. 50-247, vols. I and II, September 1972.

5.2 Distribution of Striped Bass Eggs, Larvae, and Juveniles in the Hudson River

5.2.1 General

ORNL has considered in some detail (a) spawning and distribution of eggs, (b) distribution of larvae and juveniles, and (c) factors contributing to larval distribution (IP3 FES, Appendix B, pp. B-2 to B-31). That discussion, which is summarized below, was based primarily on an analysis of data from the 1966-1968 Hudson River fisheries investigations, although earlier studies were cited where appropriate. Figure 5.2.1 may be used as a reference for this discussion of spatial distributions.

Each spring, adult striped bass migrate upstream and enter the fresh-water portion of the river, where spawning occurs as temperatures increase from about 50 to 70°F. However, the great majority of the annual egg production occurs during the period of time when temperature increases from about 58 to 62°F. Thus the longitudinal distribution of the egg production in the estuary is partly controlled by temperature.

The eggs and larvae drift with the currents in a net downstream direction but tend to concentrate in a region of low salinity. The juvenile bass grow slowly at first. Although they become increasingly less susceptible to passive transport over the first six to eight weeks, during this period they are subject to entrainment by the intakes of the once-through cooling systems. At the end of their planktonic stage, the young bass begin to move into shoal areas with a water depth of 20 ft or less. The importance of such shoals is apparent from the high concentrations of young bass in the shallow trawl stations and beach seine stations. These areas serve as the major nursery grounds where the juvenile bass grow rapidly. The major such nursery area in the Hudson River occurs below the power plants in Haverstraw Bay and the Tappan Zee.

The suggestion that the downstream transport of young-of-the-year striped bass is composed of older juveniles that are not susceptible to entrainment is not supported by the available data. The peak abundance of young-of-the-year striped bass below most of the power plants generally occurs in late July and early August. Furthermore, the peak abundance in the smaller upstream nursery areas does not precede the peak downstream; instead, the two coincide. In addition, the disappearance of larvae from plankton nets and surface trawls coincides with their appearance in shoals and the shallow areas that can be sampled with beach seines.

5.2.2 Texas Instruments 1973 and 1974 data

The following material has been excerpted from Sect. VI of Texas Instruments, Inc., *First Annual Report for the Multiplant Impact Study of the Hudson River Estuary*, July 1975. This material provides an

Fig. 5.2.1. The Hudson River showing major existing and planned power generating plants. Adapted from Quirk, Lawler and Matusky Engineers, "Hudson River Water Quality and Waste Assimilative Capacity Study," December 1970.

informative summary of the major findings from more recent data and discusses the similarities and differences between the 1973 and 1974 data on the distribution and abundance of early life stages of striped bass in the Hudson River estuary.

DISCUSSION

The general trends in the abundance and distribution patterns of the early life stages (egg through juvenile) of striped bass in the Hudson River estuary during 1973 and 1974 reveal several similarities as well as differences -- many of which represent real differences. Some differences, however, are likely the result of improvements in the longitudinal river ichthyoplankton-sampling program initiated in 1974. The two major improvements were increased sampling effort in the shoals stratum and night only sampling beginning during the period 12-17 June (for details, refer to Section III). Consequently, standing-crop differences of life stages cannot be directly compared between years.

The beach-seine survey sampling designs were similar in 1973 and 1974; therefore, juvenile standing crops calculated from beach-seine catches in both years can be directly compared. This section presents identification and discussion of the real and nonreal differences in abundance and distribution in 1973 and 1974.

The 1973 and 1974 longitudinal river ichthyoplankton-sampling programs were designed to collect striped bass early life stages, particularly eggs and yolk-sac larvae. Eggs and yolk-sac larvae were concentrated on the bottom and channel strata (Table [5.2.1]); they are pelagic and accessible to sampling gear that operates effectively near the bottom. Post yolk-sac larvae are also concentrated primarily in the bottom and channel strata but 10.9% of the estimated post yolk-sac larvae standing crops in 1974 occurred in the shoals stratum. Juveniles were almost evenly divided between the shoals and the bottom and channel strata. Therefore, the modified 1974 ichthyoplankton-sampling program which included more effort in the shoals stratum and shifted the sampling to the night hours in mid-June has provided insight on striped bass activity in the shoals and should have increased the efficiency of capturing the motile post yolk-sac larvae and juveniles.

Table 5.2.1. Mean percentage of all standing-crop estimates of striped bass early life stages occurring in shoals stratum [<20 ft (6 m) deep] by ichthyoplankton gear during 1974 (April 29-August 15)

Eggs	Yolk-sac larvae	Post-yolk-sac larvae	Juveniles
5.3	4.7	10.9	44.3

Comparisons between 1973 and 1974 striped bass egg and yolk-sac larvae standing crops are the most valid comparisons of all the early life stages. Post yolk-sac larval and juvenile standing crops in 1973 were probably biased low because these life stages are more concentrated in the shoals than egg or yolk-sac larvae. The increased shoal and night sampling in 1974 likely reduced gear avoidance and increased the catches of post yolk-sac larvae and juveniles.

Juvenile standing crops based on beach-seine catches are directly comparable between the two years; however, daytime catch estimates appeared to be underestimates of juvenile striped bass in the shore zone in 1974. Night beach-seine standing crops in four geographical regions (Croton/Haverstraw, Indian Point, West Point, and Cornwall) were significantly higher (Wilcoxon Signed-Rank Test, $p < 0.01$) than daytime standing-crop estimates in these regions for the same time intervals (Figures D-23 and D-24).^{*} The length-frequency distributions were similar (Tables D-175 and D-179),^{*} indicating that gear avoidance was either nonexistent or comparable between day and night sampling. Juvenile striped bass apparently moved into the shore zone in greater numbers at night, at least after 4 August 1974, in the Croton/Haverstraw through Cornwall regions.

There were two basic differences in striped bass longitudinal distribution and abundance in 1973 and 1974. Peak egg abundance was similar in both years but the distribution extended further upstream through the Poughkeepsie-Hyde Park region in 1973. Egg abundance was relatively high in the Indian Point and West Point regions in both 1973 and 1974. Peak juvenile standing crops in 1974 were only about 25% as large as 1973 standing crops although the distribution patterns were similar. Because egg and larvae standing crops were basically similar in 1973 and 1974, the low juvenile abundance in 1974 suggests a decline in the population during the transition from the post yolk sac larvae to juvenile life stages.

During 1974, peak yolk-sac larvae and post yolk-sac larvae standing crops occurred two and four weeks after the peak egg period, respectively, but further upstream. This apparent upriver displacement suggests a hydrologic transport mechanism(s); however, another explanation is plausible. Egg incubation time in early to mid-June should have been shortened by the near 20°C water temperatures. Consequently, several egg depositions could have occurred between the ichthyoplankton river runs and not be sampled. Life stage duration of yolk-sac larvae and post yolk-sac larvae at various temperatures are unknown but both stages are probably of longer duration than the eggs at water temperatures near 20°C.

Striped bass juveniles in 1974 appeared to move into the shoal stratum after they metamorphosed from the post yolk-sac larvae stage. Only 10.9% of all standing-crop estimates of post yolk-sac larvae based on ichthyoplankton occurred in the shoal stratum, but the percentage of juveniles in the shoals increased to 44.3% (Table

^{*} Not reproduced for this excerpt.

[5.2.1]). The shoals stratum represents only about 10% of the total river volume. During July, about 80% of the juvenile standing crops taken in ichthyoplankton gear came from the shoals stratum, about the same time that juvenile standing crops were increasing in the shore zone (Table D-143).^{*} Standing crops in the shore zone increased to a peak in late August concomitant with a decrease in the standing crops in the bottom, channel, and shoal areas (Fig. [5.2.2]). These data support the hypothesis that striped bass young move from the channel to the shoals and shore zone after they transform into juveniles, but the movement is apparently gradual as the population moves downstream.

Fig. 5.2.2. Distribution of juvenile striped bass in shoals and shore zone in 1974.

^{*} Not reproduced for this excerpt.

5.3 Entrainment Mortality Factor (f_c)

The entrainment mortality factor (f_c) is defined as the fraction of entrained live organisms killed as a result of passage through the plant. This mortality may be direct (immediate or latent) or indirect. Latent entrainment mortality refers to inevitable differential mortality of entrained vs control organisms due to factors such as physical or physiological damage. Indirect entrainment mortality refers to the differential death of entrained organisms due to extrinsic factors (e.g., increased vulnerability to predators). In general, f_c is estimated for each entrainable life stage considered and, where possible, for each plant in models used to estimate the annual percentage reduction of young-of-the-year fish.

5.3.1 Equations for calculating f_c

Values of f_c are based on information from sampling of organisms from the intakes and the condenser discharge streams of operating power plants. Young-of-the-year striped bass (except eggs) in each sample are classified as "live," "stunned," or "dead." Information about and results from the sampling programs can be found in refs. 1-4. The term "alive" refers to either "live" or "stunned" organisms.

In the IP3 FES (pp. V-87 and V-88),⁵ ORNL developed the following equation for estimating the probability of short-term survival upon passage through the condenser cooling system. This equation is then used to provide estimates for each of the entrainable life stages. Define:

P_I = probability of an organism being live in the intake. The assumption is made that no organisms in the intake are stunned before being collected.

P_D = probability of an organism live in the intake being live in the discharge canal after passage through the plant.

P_S = probability of an organism live in the intake or discharge canal being classified "live" in the Pyrex sorting dish after collection from the intake or discharge canal.

Then the probability of any organism being classified as "live" in the intake sample, P_{IS} , is

$$P_{IS} = P_I \times P_S,$$

and the probability of being classified as "live" in the discharge-canal sample, P_{DS} , is

$$P_{DS} = P_I \times P_D \times P_S = P_{IS} \times P_D ,$$

assuming P_S is the same for intake and discharge-canal samples.

Thus the probability of an organism live in the intake being live in the discharge canal after passage through the plant, P_D , is (from the preceding two expressions)

$$P_D = P_{DS}/P_{IS} ,$$

and the probability of short-term mortality upon passage through the plant, $f_{c,s}$, is

$$f_{c,s} = 1 - P_D = 1 - P_{DS}/P_{IS} = (P_{IS} - P_{DS})/P_{IS} . \quad (5.3-1)$$

P_{IS} and P_{DS} are estimated by calculating the fraction or percentage of organisms classified as live from counts of the total number of organisms classified as live, stunned, and dead in intake and discharge-canal samples respectively. This procedure incorporates automatic correction for organisms that are already dead before entering the intake area and for the stunning or mortality of organisms due to the sampling process, if the sampling process is identical with respect to the stunning and killing of organisms at the intake vs at the discharge. If net damage is more severe at the discharge (as may be the case at Indian Point) or if plant-stunned organisms are actually viable, however, the formula tends to overestimate $f_{c,s}$. The formula is also sensitive to assumptions about gear avoidance and extrusion.

Values of $f_{c,s}$ calculated using this formula are estimates of short-term mortality and do not include consideration of possible differential delayed mortality and increased susceptibility to predation of organisms classified as "live." The probability of short-term survival is $1.0 - f_{c,s}$. ORNL's judgment is that the probability of long-term survival, P_{SE} , is lower than the probability of short-term survival by a fraction k (i.e., $P_{SE} = [1 - f_{c,s}] - k[1 - f_{c,s}]$). ORNL's final estimate in the IP3 FES of f_c (designated $\hat{f}_c$, the probability of long-term mortality due to entrainment) was therefore (assuming that $k = 0.1$)

$$\hat{f}_c = 1 - P_{SE} = 0.1 + 0.9f_{c,s} . \quad (5.3-2)$$

Lawler, Matusky, and Skelly Engineers (LMS) and Ecological Analysts, Inc., calculate their final cropping factor using Eq. (5.3-1) but not Eq. (5.3-2).

5.3.2 Review of information in the IP3 FES

Detailed information on entrainment mortality was available to ORNL at the time of preparation of IP3 FES only from New York University's 1973 studies.¹ Using the NYU data and Eq. (5.3-1) for the probability

of short-term mortality after passage through the plant, the following estimates of f_c were calculated for each entrainable striped bass life stage (Table 5.3.1): 0.78 for eggs, 0.57 for yolk-sac larvae, 0.57 for larvae, and 0.69 for entrainable juveniles. Values of P_{SE} (the long-term probability of surviving entrainment) were also presented (Table 5.3.1), and the values of f_c from Eq. (5.3-2) have been added to Table 5.3.1 for the sake of clarity. Estimates of 95% confidence intervals for these $\hat{f}_c$ values are not available at present. These $\hat{f}_c$ values reflect mortality due to pressure changes and other mechanical effects alone, because during the 1973 sampling periods there was no chlorination and, for the most part, no ΔT . During periods of chlorination, the $\hat{f}_c$ values would be higher for all life stages. With a ΔT , the $\hat{f}_c$ values would be approximately the same or higher, depending on the ambient temperature. For example, during operation at high power levels, the temperatures in the discharge canal at Indian Point will exceed 90°F beginning approximately in late June or early July. As the exposure temperature increases from approximately 85°F to approximately 95°F, ORNL expects that $\hat{f}_c$ will approach 1.0 for all life stages of striped bass.

5.3.3 New information

ORNL has received the results of New York University's 1974 studies at Indian Point² and has recently received the results of studies conducted by Ecological Analysts, Inc. (EA) at Bowline³ and partial results of their study at Roseton.⁴

5.3.3.1 1974 studies at Indian Point. New York University's 1974 studies at Indian Point² were fundamentally similar to the 1973 studies. Organisms were collected from the intake and discharge areas using nets with a mouth opening of 0.5 m. As was the case in 1973, intake sampling was conducted at the intakes of Units 1 and 2. Shorter nets were used at the Unit 2 intakes (1.2 m) than at Unit 1 intakes or at the discharge stations (1.9 m) because of space limitations. Figure 5.3.1 shows schematically the various locations of sampling in the 1974 program.

The 1974 program differed from the 1973 program in that no daytime samples were taken, shorter sampling times were used, flowmeters were not installed in the nets, and velocity reduction cones (VRCs) were used to reduce the net mouth opening. According to a separate flume study,⁶ VRCs typically tapered from 0.5 m at the mouth of the net to 0.35 m at a distance of 0.146 m in front of the net for the intake nets and from 0.5 to 0.17 m for the discharge nets.

Striped bass collected were classified by life stage as "live," "stunned," or "dead," except for eggs, which were classified as "live" or "dead." Latent mortality studies (to 72 hr) were conducted separately on most of the live and stunned post-yolk-sac larvae and the live juveniles from both the intake and the discharge samples. There were no stunned juveniles at the intakes, and latent mortality results for stunned juveniles from the discharge stations are not presented.

Table 5.3.1. Estimation of the probability of short-term and long-term mortality upon entrainment for the nonscreenable life stages of striped bass based on 1973 data at Indian Point with no chlorination and, for the most part, with no ΔT

Life stage	Unit No. 1, Intakes 1 and 2 ^a		Discharge canal ^a			f_c^b	P_{SE}^c	$\hat{f}_c^d$
			Percent live					
	Number	Percent live	Number	Stations	Stations			
				D-1 and D-2	D-1, D-2, and DP			
Eggs	946	60.4	616	13.5		0.78	0.20	0.80
Yolk-sac larvae	132	26.3	99	11.3		0.57	0.39	0.61
Larvae	849	31.7	3516		13.7	0.57	0.39	0.61
Juveniles	153	68.3	785		21.4	0.69	0.28	0.72

^aNumbers of organisms and percent live values are from NYU (1974).

$$b_{f_c} = \frac{(\text{mean percent live in intake}) - (\text{mean percent live in discharge canal})}{(\text{mean percent live in intake})}$$

$$^cP_{SE} = 0.9(1 - f_c).$$

$$^d\hat{f}_c = 1 - P_{SE}.$$

Source: IP3 FES, p. V-89, based on New York University, Institute of Environmental Medicine, Hudson River Ecosystem Studies, *Effects of Entrainment by Indian Point Power Plant on Biota in the Hudson River Estuary, Progress Report for 1973*, prepared for Consolidated Edison Company of New York, Inc., September 1974, Tables 7-3 and 7-4.

Fig. 5.3.1. Schematic diagram of Indian Point cooling water system showing locations of NYU's sampling stations in 1974. Source: New York University, Institute of Environmental Medicine, *Hudson River Ecosystem Studies, Effects of Entrainment by the Indian Point Power Plant on Biota in the Hudson River Estuary, Progress Report for 1974*, prepared for Consolidated Edison Company of New York, Inc.; February 1976, Fig. 1-9.

The key results of these studies are summarized by ORNL as follows:

1. The numbers of striped bass by life stage and by condition caught at various stations are shown in Table 5.3.2.
2. Striped bass density (numbers per 1000 m³ of water filtered) was compared only between intake stations. Relatively more eggs were collected per unit volume sampled at the Unit 2 station (II-2) than at the Unit 1 stations (I-1 and I-2). No significant differences in striped bass density were found for other life stages between the intake stations.
3. Significant differences between locations in initial mortality of the various life stages are shown in Table 5.3.3. Judgments of significant differences in this table are based on analysis of variance (ANOVA) using values transformed to natural logarithms.
4. Based on the individual samples, initial percent live, stunned, or dead values with 95% confidence intervals were calculated. These values are presented in Table 5.3.4. Because these values are based on individual samples, they differ slightly from values which would be obtained from the total abundance data presented in Table 5.3.2.
5. The results of individual comparisons between stations are presented in Table 5.3.5. In some cases, the differences in this table appear to contradict differences in Table 5.3.3. For example, Table 5.3.3 indicates no significant differences in the proportion of yolk-sac larvae dead (dead/total caught), while Table 5.3.5 indicates significant differences between I and D-2 and between I and DP stations. This apparent contradiction may result from a statistical subtlety.
6. The following passage is quoted from ref. 2, p. 273:

For all life stages, the proportion dead increased with distance downstream in the cooling water flow from intake stations through station D-2. This indicates that the time/temperature exposure of life stages of striped bass at the Indian Point plant is cumulative and that the additional time of exposure to warm water between D-1 and D-2 increases the probability of death. A significant increase in the proportion of stunned and dead larvae was noted between D-1 and DP stations, but so few organisms were collected at DP-3 and DP-8 that conclusions must be treated with care.

ORNL agrees in principle that mortality is likely to increase as organisms move further down the discharge canal, although the data in Table 5.3.3-5.3.5 do not appear to fully correspond to NYU's conclusion as quoted.

7. Hatchability of entrained eggs and percent survival of entrained larvae and juveniles after 72 hr are tabulated in Tables 5.3.6 and 5.3.7 respectively. Figure 5.3.2 shows the pattern of latent survival for larvae and juveniles over time. Analysis of the data using 2 by 2

Table 5.3.2. Total abundance of live, stunned, and dead striped bass eggs, yolk-sac larvae, larvae, and juveniles collected during plant entrainment sampling in 1974

(I-1, I-2: Unit 1 intake bays 1 and 2; II-2: Unit 2 intake bay 2;
I: intake average; D-1, D-2: discharge-canal stations 1 and 2;
DP-3, DP-8: discharge ports 3 and 8; DP: discharge-port average)

Station	Eggs			Yolk-sac larvae			
	Live	Dead	Total	Live	Stunned	Dead	Total
I-1, I-2	204	260	464				
II-2	294	210	504				
I				15	54	127	196
D-1	30	79	109	0	2	14	16
D-2	29	89	118	0	0	23	23
DP	1	7	8	0	0	1	1
Total ^a	(561)	(646)	(1207)	15	56	(163)	(234)
	558	645	1203			165	236

Station	Larvae				Juveniles			
	Live	Stunned	Dead	Total	Live	Stunned	Dead	Total
I	141	243	270	654	25	0	0	25
D-1	22	34	255	311	3	9	3	15
D-2	3	6	83	92	3	1	0	4
DP-3	0	0	37	37	1	1	1	3
DP-8	0	0	20	20				
Total ^a	(170)	283	(656)	(1109)	(31)	11	4	(46)
	166		665	1114	32			47

^aTotals from the original source, which appear to have been in error, are placed in parentheses, with the apparent correct total indicated below.

Source: New York University, Institute of Environmental Medicine, *Hudson River Ecosystem Studies, Effects of Entrainment by the Indian Point Power Plant on Biota in the Hudson River Estuary, Progress Report for 1974*, prepared for Consolidated Edison Company of New York, Inc., February 1976, Table 7-18.

Table 5.3.3. Significant differences between sampling stations in initial mortality for four life stages of striped bass collected during 1974 Indian Point entrainment studies

(I-1, I-2: Unit 1 intake samples; II-2: Unit 2 intake samples; D-1, D-2: discharge-canal samples; DP-3, DP-8: discharge-port samples)

Life stage	Dead/total caught	Stunned/total caught	Dead/stunned
Eggs ^a	(I-1, I-2) > II-2 D-1 > (I-1, I-2) D-2 > (I-1, I-2) D-1 > D-2 D-2 > II-2		
Yolk-sac larvae	None	None	D-2 > intakes
Larvae	D-1 > intakes D-2 > intakes DP-3 > intakes DP-8 > intakes	None	D-1 > intakes D-2 > intakes DP-3 > intakes DP-8 > intakes
Juveniles	None	D-1 > intakes	None

^aEggs are not classified as stunned.

Source: New York University, Institute of Environmental Medicine, *Hudson River Ecosystem Studies, Effects of Entrainment by the Indian Point Power Plant on Biota in the Hudson River Estuary, Progress Report for 1974*, prepared for Consolidated Edison Company of New York, Inc., February 1976, Table 7-16.

Table 5.3.4. Initial percent live, stunned, and dead values of striped bass from 1974 Indian Point entrainment sampling, with 95% confidence intervals

(Data are mean percentages for sampling stations.

I-1, I-2: Unit 1 intake; II-2: Unit 2 intake;

D-1, D-2: discharge-canal samples;

DP-3, DP-8: discharge-port samples;

DP: average discharge-port samples;

n: number of samples)

Station	Percent live	Percent stunned	Percent dead	n
<u>Eggs</u>				
I-1, I-2	39 ± 9		61 ± 9	86
II-2	55 ± 11		46 ± 11	49
D-1	19 ± 13		81 ± 13	25
D-2	30 ± 14		70 ± 14	32
DP	7 ± 17		93 ± 17	5
<u>Yolk-sac larvae</u>				
Intakes	8 ± 5	32 ± 9	56 ± 9	93
D-1	9 ± 20	18 ± 27	73 ± 31	11
D-2	0 ± 0	0 ± 0	100 ± 0	17
DP	0 ± 0	0 ± 0	100 ± 0	1
<u>Larvae</u>				
Intakes	26 ± 6	31 ± 6	44 ± 7	149
D-1	10 ± 6	10 ± 5	79 ± 8	74
D-2	9 ± 9	11 ± 9	80 ± 12	39
DP-3	0 ± 0	0 ± 0	100 ± 0	12
DP-8	0 ± 0	0 ± 0	100 ± 0	4
<u>Juveniles</u>				
Intakes	100 ± 0	0 ± 0	0 ± 0	18
D-1	21 ± 25	63 ± 30	17 ± 20	12
D-2	75 ± 69	25 ± 69	0 ± 0	4
DP-3	33 ± 106	33 ± 106	33 ± 106	3

Source: New York University, Institute of Environmental Medicine, *Hudson River Ecosystem Studies, Effects of Entrainment by the Indian Point Power Plant on Biota in the Hudson River Estuary, Progress Report for 1974*, prepared for Consolidated Edison Company of New York, Inc., February 1976, Table 7-17.

Table 5.3.5. Comparisons of the initial percent live, percent stunned, and percent dead for striped bass samples collected during Indian Point 1974 entrainment studies

Station means being compared are indicated within brackets between lower and upper limits of the 95% confidence interval for that comparison.

(I-1, I-2: Unit 1 intakes; II-2: Unit 2 intake; D-1, D-2: discharge-canal stations; DP: discharge-port stations)

Comparison ^a	Difference ^b
<u>Eggs, percent live</u>	
2.6 < [(I-1, I-2) - II-2] < 29.6*	16.1
4.5 < [(I-1, I-2) - D-1] < 35.0*	19.7
-7.5 < [(I-1, I-2) - D-2] < 25.4	8.9
14.9 < [(I-1, I-2) - DP] < 50.2*	32.5
19.4 < [II-2 - D-1] < 52.5*	35.8
7.5 < [II-2 - D-2] < 42.5*	25.0
30.3 < [II-2 - DP] < 67.0*	48.6
-8.0 < [D-1 - D-2] < 29.6	10.8
-6.6 < [D-1 - DP] < 32.2	12.8
3.5 < [D-2 - DP] < 43.8*	23.6
<u>Yolk-sac larvae, percent live</u>	
-19.4 < [I - D-1] < 21.7	1.2
2.9 < [I - D-2] < 12.9*	7.9
3.0 < [I - DP] < 12.9*	7.9
-11.2 < [D-1 - D-2] < 29.3	9.1
-11.2 < [D-1 - DP] < 29.3	9.1
0.0 < [D-2 - DP] < 0.0	0.0
<u>Yolk-sac larvae, percent stunned</u>	
-14.0 < [I - D-1] < 42.1	14.1
23.3 < [I - D-2] < 41.2*	32.3
23.3 < [I - DP] < 41.2*	32.3
9.0 < [D-1 - D-2] < 45.3	18.2
-9.0 < [D-1 - DP] < 45.3	18.2
0.0 < [D-2 - DP] < 0.0	0.0
<u>Yolk-sac larvae, percent dead</u>	
-18.1 < [I - D-1] < 46.1	13.9
31.8 < [I - D-2] < 50.7*	41.3
31.3 < [I - DP] < 50.7*	41.3
-4.1 < [D-1 - D-2] < 58.6	27.3
-4.1 < [D-1 - DP] < 58.6	27.3
0.0 < [D-2 - DP] < 0.0	0.0

Table 5.3.5 (continued)

Comparison	Difference
<u>Larvae, percent live</u>	
7.6 < [I - D-1] < 23.8*	15.7
6.1 < [I - D-2] < 27.5*	16.8
19.8 < [I - DP-3] < 31.7*	25.7
19.8 < [I - DP-8] < 31.7*	25.7
-9.4 < [D-1 - D-2] < 11.7	1.1
4.4 < [D-1 - DP-3] < 15.8*	10.1
4.4 < [D-1 - DP-8] < 15.8*	10.1
-0.02 < [D-2 - DP-3] < 18.0	9.0
-0.02 < [D-2 - DP-8] < 18.0	9.0
0.0 < [DP-3 - DP-8] < 0.0	0.0
<u>Larvae, percent stunned</u>	
12.2 < [I - D-1] < 28.1*	20.2
8.7 < [I - D-2] < 31.2*	20.0
24.5 < [I - DP-3] < 36.8*	30.7
24.5 < [I - DP-8] < 36.8*	30.7
-10.5 < [D-1 - D-2] < 10.9	0.2
2.7 < [D-1 - DP-3] < 18.3*	10.5
2.7 < [D-1 - DP-8] < 18.3*	10.5
1.2 < [D-2 - DP-3] < 20.1*	10.7
1.2 < [D-2 - DP-8] < 20.1*	10.7
0.0 < [DP-3 - DP-8] < 0.0	0.0
<u>Larvae, percent dead</u>	
25.8 < [I - D-1] < 45.9*	35.8
22.8 < [I - D-2] < 50.7*	36.7
36.8 < [I - DP-3] < 50.3*	56.4
36.8 < [I - DP-8] < 50.3*	56.4
-13.4 < [D-1 - D-2] < 15.2	0.9
71.8 < [D-1 - DP-3] < 87.1*	20.6
71.8 < [D-1 - DP-8] < 87.1*	20.6
68.1 < [D-2 - DP-3] < 92.5*	19.7
68.1 < [D-2 - DP-8] < 92.5*	19.7
0.0 < [DP-3 - DP-8] < 0.0	0.0

* Indicates a significant difference between means.

^a Station means being compared are indicated within brackets between the the lower and upper limits of the 95% confidence interval for that comparison.

^b Absolute difference between the station means indicated within brackets in the column headed "Comparison."

Source: New York University, Institute of Environmental Medicine, *Hudson River Ecosystem Studies, Effects of Entrainment by the Indian Point Power Plant on Biota in the Hudson River Estuary Progress Report for 1974*, prepared for Consolidated Edison Company of New York, Inc., February 1976, Table 7-19.

Source: New York University, Institute of Environmental Medicine, *Hudson River Ecosystem Studies, Effects of Entrainment by the Indian Point Power Plant on Biota in the Hudson River Estuary Progress Report for 1974*, prepared for Consolidated Edison Company of New York, Inc., February 1976, Table 7-19.

Table 5.3.6. Number and percentage of striped bass eggs hatching from total of live eggs collected at the Indian Point plant in 1974

Station	Total live eggs collected	Total eggs hatched	Percentage of eggs hatched
Intake	297	190	63.9
Discharge	61 ^a	29	47.5

^aThe reason for the discrepancy between this number and the data in Table 5.3.2 (which indicate 60 live eggs collected from the discharge stations) is not known.

Source: New York University, Institute of Environmental Medicine, *Hudson River Ecosystem Studies, Effects of Entrainment by the Indian Point Power Plant on Biota in the Hudson River Estuary, Progress Report for 1974*, prepared for Consolidated Edison Company of New York, Inc., February 1976, Table 7-20.

Table 5.3.7. Survival of entrained striped bass larvae and juveniles after a three-day holding period: 1974 data from Indian Point

Life stage	Source	Initial condition	Initial number	Number surviving	Percent survival
Larvae	Intake	Live	152	53	34.8 (34.9) ^a
	Discharge	Live	23	11	47.8
Larvae	Intake	Stunned	234	10	4.2 (4.3) ^a
	Discharge	Stunned	39	1	2.5 (2.6) ^a
Juveniles	Intake	Live	24	21	87.5
	Discharge	Live	7	6	85.7

^aValues that are rounded correctly are given in parentheses.

Source: New York University, Institute of Environmental Medicine, *Hudson River Ecosystem Studies, Effects of Entrainment by the Indian Point Power Plant on Biota in the Hudson River Estuary, Progress Report for 1974*, prepared for Consolidated Edison Company of New York, Inc., February 1976, Table 7-21.

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Fig. 5.3.2. Percent survival of striped bass collected from the intake and the discharge of Indian Point (1974 data). (A) Post-yolk-sac larvae initially classified as "live" (nonstunned), (B) juveniles initially classified as "live" (nonstunned), (C) post-yolk-sac larvae initially classified as stunned. The solid horizontal lines were drawn by ORNL in order to extract certain values from these graphs for use in calculations of entrainment mortality (Sect. 5.3.5.2). Source: New York University, Institute of Environmental Medicine, *Hudson River Ecosystem Studies, Effects of Entrainment by the Indian Point Power Plant on Biota in the Hudson River Estuary, Progress Report for 1974*, prepared for Consolidated Edison Company of New York, Inc., February 1976, pp. 278-280.

contingency tables did not show a significant difference between the intakes and discharges with respect to survival of "live" larvae or juveniles after 24, 48, or 72 hr. The report does not state whether the survival of initially "stunned" larvae is significantly different for the intake vs the discharge or from initially "live" larvae. Tabulated values for intermediate survival (at 24 and 48 hr) were not supplied, and ORNL has not attempted to reconstruct these from the graphs, except when needed in Sect. 5.3.5.

Interpretation of these results is somewhat hampered by a lack of information about specific ΔT and chlorination conditions, by a lack of velocity information at intakes and particularly at discharge stations, by a lack of information concerning the operation of Unit 3 pumps (which could affect sampling in the discharge canal), and by a lack of data other than the summary data which have been presented. For the purposes of calculating f_c values (later in Sect. 5.3.5), ORNL has used the data in Tables 5.3.2, 5.3.6, and 5.3.7.

5.3.3.2 1975 studies at Bowline Point. Ecological Analysts, Inc. (EA) conducted entrainment survival studies at Bowline Point in 1975, utilizing a relatively new sampling method.³ The method involved pumping water from the intake area or from the discharge pipe into larval collection tables (originally designed by Lawler, Matusky, and Skelly Engineers). Figure 5.3.3 is a perspective drawing of a standard larval table. Sampling was designed to coincide with high larval abundance. From June 3 to June 23, sampling was conducted four times per week during the night, when larval and early juvenile stages were more abundant. After June 23, the sampling effort was reduced to one or two days per week, and samples were collected during both day and night. Details of the program can be found in ref. 3.

Discharge sampling was restricted to the Bowline Unit 2 discharge pipe. Because the two units at Bowline share a common intake structure, there are fewer problems of sample comparability compared to the situation at Indian Point. Data are presented simply as being from "intake" or "discharge" samples.

Plant operating conditions varied considerably during the sampling, representing, for the most part, relatively low ΔT s.

Key results from the study relating to striped bass are summarized below by ORNL.

1. Table 5.3.8 shows the number of fish, initial fractions alive ("live" and "stunned" combined), and latent survival (expressed as fractions of the total number collected) for striped bass post-yolk-sac larvae collected from the intake and the discharge. ORNL notes that these numbers (141 at intake and 111 at the discharge) are smaller than the numbers collected at these stations according to other tables in ref. 3, Vol. II (one of these, Table 3.2.1a, lists 219 striped bass post-yolk-sac larvae from the intake). Insufficient numbers of other life stages were collected for reliable estimates of survival to be made.

Fig. 5.3.3. Standard two-screen larval table as used in entrainment survival sampling by Ecological Analysts at Bowline Point and Roseton in 1975. Scale, 1:40. Source: Ecological Analysts, Inc., *Bowline Point Generating Station*, vol. I, *1975 Annual Interpretive Report*, Part I: *Entrainment Survival*, July 1976, prepared for Orange and Rockland Utilities, Inc., New York, 1976, Fig. 3.2.1a.

Table 5.3.8. Mean initial and latent survival of striped bass post-yolk-sac larvae at the Bowline Point plant intake and discharge, 1975

Station	Total number of fish	Fractions alive ^a at various times since collection							
		Initial	3 hr	6 hr	12 hr	24 hr	48 hr	72 hr	96 hr
Intake	141	0.81	0.54	0.44	0.42	0.38	0.37	0.35	0.30
Discharge	111	0.74	0.50	0.40	0.35	0.34	0.32	0.29	0.23

^aAlive: all individuals showing signs of life ("live" and "stunned").

Source: Ecological Analysts, Inc., *Bowline Point Generating Station*, vol. I, 1975 *Annual Interpretive Report*, Part I: *Entrapment Survival*, July 1976, prepared for Orange and Rockland Utilities, Inc., New York, 1976, Table 3.3-2.

2. The pattern of latent survival was not shown to differ at the 0.05 level of significance for organisms from the intake vs those from the discharge, using two least-squares regression approaches. (These tests were apparently applied to combined "live" plus "stunned" larvae from each location.)

3. Stunned larvae, from both the intake and the discharge, appeared to die more rapidly than nonstunned larvae.

4. Initial and latent survival of white perch post-yolk-sac larvae (live and stunned combined) was higher for the discharge vs the intake samples. Striped bass data were combined with white perch data for an examination of the effects of a plant temperature rise (ΔT) on through-plant survival (Table 5.3.9). The data were considered insufficient in general to allow interpretation of temperature effects with any reasonable degree of confidence.

Because length-frequency data from this study were available, ORNL has plotted the length-frequency distribution for striped bass post-yolk-sac larvae collected from the intake and also from the discharge (Fig. 5.3.4). These data indicate that larvae collected from the discharge tend to be slightly larger than those collected from the intake. Because older larvae can be expected to have a higher survival rate, a modest bias may exist in the latent survival comparisons, resulting in a better indicated relative survival of larvae from the discharge than is actually the case. We note that Fig. 4.3.1, Part II, Vol. I, ref. 3, indicates a different length-frequency distribution for the discharge, which, if actually representative of the entrainment survival samples, would accentuate this bias.

5.3.3.3 1975 studies at Roseton. Ecological Analysts, Inc., conducted entrainment mortality sampling at Roseton in 1975 using collection techniques similar to those discussed in Sect. 5.3.3.2.⁴ Larvae held for latent survival studies were fed live brine shrimp, in contrast to the parallel studies at Indian Point and Bowline Point, where larvae were apparently not fed. ΔT conditions were variable, but for striped bass, they represented substantially less than those expected for full-power operation. There has been no need to chlorinate during the entrainment season at Roseton.

Sampling at Roseton began on May 29. Between then and the first week in July, which includes nearly all the striped bass data, samples were taken four nights per week from dusk to dawn, with an average of ten samples taken per station per night. Details of the program can be found in ref. 4.

The key results from this study relating to striped bass are summarized below by ORNL. Although "alive" larvae were (according to the "Methods" section of ref. 4) initially classified as "live" or "stunned" (using ORNL's terminology rather than EA's), data are not presented broken down into these categories. All conclusions are apparently based on combined "live" and "stunned" organisms.

Table 5.3.9. Initial percent survival and percent of total sample still alive at 96 hr for combined striped bass and white perch larvae as a function of plant operation at the Bowline Point plant in 1975

(Values in parentheses are apparently total numbers of larvae, whether alive or dead)

Time	Station	Percent alive ^a and (in parentheses) total sample size at each temperature range				
		<0.5°C	1.0-4.0°C	4.5-6.0°C	6.5-8.0°C	8.5-12.5°C
Initial	Intake	43(14)	75(152)	85(27)	74(39)	38(26)
	Discharge	63(16)	69(184)	84(31)	66(25)	78(18)
96 hr	Intake	22	27	30	28	19
	Discharge	19	27	36	19	11

^aAlive: all individuals showing signs of life ("live" and "stunned").

Source: Ecological Analysts, Inc., *Bowline Point Generating Station*, vol. I, 1975 *Annual Interpretive Report*, Part I: *Entrainment Survival*, July 1976, prepared for Orange and Rockland Utilities, Inc., New York, 1976, Table 3.3-6.

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Fig. 5.3.4. Length-frequency distribution of striped bass larvae collected in pumped samples from Bowline Point in 1975. Intake, dashed lines; discharge, solid lines. Source: Ecological Analysts, Inc., *Bowline Point Generating Station*, vol. II, *1975 Annual Data Report*, November 1976, prepared for Orange and Rockland Utilities, Inc., New York, 1976, Tables 3.2.4a and 3.2.4b.

1. Table 5.3.10 shows the number of fish, the initial fraction alive, and the survival to 96 hr. ORNL notes that the total numbers for yolk-sac larvae, post-yolk-sac larvae, and juveniles in this table (21, 272, and 10, respectively) are less than the total number collected (30, 392, and 11) as tabulated in ref. 4, Table 4.3-1.

2. A binomial test for differences between two proportions showed a significant difference at the 0.05 level of significance between the intake and discharge in initial survival of yolk-sac larvae and in both initial and 96-hr survival of post-yolk-sac larvae.

3. Figure 5.3.5 shows the pattern of initial and latent survival of striped bass post-yolk-sac larvae from intake and discharge collections.

4. ΔT s ranging (from some samples) up to 8°C, with ambient temperatures of 20 to 23°C, did not appear to significantly affect survival of striped bass post-yolk-sac larvae.

5.3.4 Modified methodology for entrainment mortality calculations

Some of this new information has prompted ORNL to explore an alternative method of calculating f_c . In particular, it is appropriate to consider the possibility that some of the stunned organisms in discharge samples were stunned as a result of passage through the plant and that these could recover and ultimately survive. In this case, the formula for calculating $f_{c,s}$ in Sect. 5.3.1 is not the appropriate one, and a modified methodology is needed.

The subscripts on the various probabilities defined below are based on the following convention. Three locations are considered: the intake (I), the discharge canal (D), and the sorting tray in which samples are placed after collection from the intake or discharge canal (T, for tray). At each of these three locations, three conditions for an organism are considered: live (L), stunned (S), and either live or stunned (A, for "alive"; see the first paragraph of Sect. 5.3.1). Subscripts are generally specified in pairs, although there may be either one or two pairs. For example, P_{IL} is the probability of an organism in the intake (I) being live (L), and $P_{IL,DL}$ is the probability of an organism live (L) in the intake (I) being live (L) in the discharge canal (D) after passage through the plant. Note that, within each pair, the subscripts are ordered so that location is specified first and then the condition of the organism. When the conditions of an organism at two locations are considered simultaneously, the location subscript is omitted. For example, $P_{L,TL}$ is the probability of a live organism (L) in either the intake or the discharge canal being classified "live" (L) in the sorting tray (T) after collection from the intake or discharge canal. When organisms are considered regardless of condition, the condition subscript is omitted. For example, $P_{D,TL}$ is the probability of any organism (which, in general, can be either alive or dead before collection) in the discharge being classified live (L) in the sorting tray (T) after collection from the discharge.

Table 5.3.10. Summary of striped bass entrainment survival at the Roseton Generating Station from May to September 1975

Station	Eggs			Yolk-sac larvae			Post-yolk-sac larvae			Juveniles		
	Number of fish	Proportion alive ^a Initially 96 hr		Number of fish	Proportion alive Initially 96 hr		Number of fish	Proportion alive Initially 96 hr		Number of fish	Proportion alive Initially 95 hr	
Intake	2	0.00	0.00	5	0.80	0.00	99	0.83	0.16	7	0.57	0.57
Discharge	0			16	0.19	0.00	173	0.61	0.06	3	1.00	0.67

^aAlive: all individuals showing signs of life ("live" and "stunned").

Source: Ecological Analyst, Inc., *Roseton Generating Station, Impingement and Entrainment Survival Studies, 1975 Annual Report*, prepared for Central Hudson Gas and Electric Company, New York, December 1976, Table 4.3-2.

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Fig. 5.3.5. Latent survival of striped bass post-yolk-sac larvae collected at the intake (N = 100) and discharge (N = 172) of the Roseton Generating Station during late May and early June of 1975. The ordinate is the percentage of the entire sample (alive and dead organisms combined). The solid horizontal lines were drawn by ORNL in order to extract certain values from this graph for use in calculations of entrainment mortality (Sect. 5.3.5.2). Source: Ecological Analysts, Inc., *Roseton Generating Station Impingement and Entrainment Survival Studies, 1975 Annual Report*, prepared for Central Hudson Gas and Electric Company, New York, December 1976, Fig. 4.3-1.

P_{IL} = probability of an organism being live in the intake. It is assumed that all organisms in the intake are either live or dead before exposure to sampling. There are no stunned organisms in the intake.

$P_{IL,DA}$ = probability of an organism live in the intake being alive (whether live or stunned) in the discharge canal after passage through the plant.

$P_{IL,DL}$ = probability of an organism live in the intake being live in the discharge canal after passage through the plant.

$P_{IL,DS}$ = probability of an organism live in the intake being stunned (but not dead) in the discharge canal as a result of passage through the plant.

$P_{IL,TL}$ = probability of a live organism in the intake being classified live in the sorting tray after collection from the intake.

$P_{IL,TS}$ = probability of a live organism in the intake being classified stunned in the sorting tray after collection from the intake.

$P_{DL,TL}$ = probability of a live organism in the discharge canal being classified live in the sorting tray after collection from the discharge canal.

$P_{DL,TS}$ = probability of a live organism in the discharge canal being classified stunned in the sorting tray after collection from the discharge canal.

$P_{DS,TL}$ = probability of an organism stunned as a result of passage through the plant being classified live in the sorting tray after collection from the discharge canal.

$P_{DS,TS}$ = probability of an organism stunned as a result of passage through the plant being classified stunned in the sorting tray after collection from the discharge canal.

Assumption 1: Plant-stunned organisms have no chance of survival.

The probability of any organism being classified as live in an intake sample, $P_{I,TL}$, is

$$P_{I,TL} = P_{IL} \times P_{IL,TL} \quad (5.3-3)$$

Recall that there are assumed to be no stunned organisms in the intake. The probability of any organism being classified as live in the discharge sample, $P_{D,TL}$, is

$$P_{D,TL} = P_{IL} \times P_{IL,DL} \times P_{DL,TL}, \quad (5.3-4)$$

assuming stunned organisms in the discharge canal are not classified as live in the sorting tray (i.e., $P_{DS,TL} = 0$). Thus, assuming

$$P_{IL,TL} = P_{DL,TL} \equiv P_{L,TL} ,$$

the probability of an organism live in the intake being live in the discharge canal after passage through the plant, $P_{IL,DL}$, is (from the preceding two expressions):

$$P_{IL,DL} = P_{D,TL} / P_{I,TL} , \quad (5.3-5)$$

and the probability of immediate mortality upon passage through the plant, $f_{c,s}$, is

$$f_{c,s} + 1 - P_{IL,DL} = 1 - \frac{P_{D,TL}}{P_{I,TL}} = \frac{P_{I,TL} - P_{D,TL}}{P_{I,TL}} . \quad (5.3-6)$$

$P_{I,TL}$ and $P_{D,TL}$ are estimated by calculating the fraction or percentage of organisms classified as live from counts of the total number of organisms classified as live, stunned, and dead in intake and discharge canal samples respectively. This procedure incorporates automatic correction for organisms which are already dead before entering the intake area and for the stunning or mortality of organisms due to the sampling process, if the sampling process is identical with respect to these factors at the intake vs the discharge. If net damage is more severe at the discharge (as may be the case at Indian Point, i.e., $P_{IL,TL} > P_{DL,TL}$), or if plant-stunned organisms are actually viable (i.e., $P_{DS,TL} > 0$) (in contrast to assumption 1), the formula tends to overestimate $f_{c,s}$. The formula is also sensitive to assumptions about gear avoidance and extrusion. It is the same formula developed in Sect. 5.3.1.

Assumption 2: Plant-stunned organisms in the discharge canal can survive as well as live organisms in the discharge canal.

In this case, the probability of any organism being classified as alive in the intake sample, $P_{I,TA}$, is

$$\begin{aligned} P_{I,TA} &= P_{IL} \times P_{IL,TL} + P_{IL} \times P_{IL,TS} = P_{IL} (P_{IL,TL} + P_{IL,TS}) \\ &= P_{IL} \times P_{IL,TA} , \end{aligned} \quad (5.3-7)$$

where

$$P_{IL,TA} = P_{IL,TL} + P_{IL,TS} .$$

Again, recall that there are assumed to be no stunned organisms in the intake. The probability of any organism being classified as alive (either live or stunned) in the discharge sample, $P_{D,TA}$, is

$$\begin{aligned}
 P_{D,TA} &= P_{IL} \times P_{IL,DL} (P_{DL,TL} + P_{DL,TS}) + P_{IL} \times P_{IL,DS} (P_{DS,TL} + P_{DS,TS}) \\
 &= P_{IL} \times P_{IL,DL} \times P_{DL,TA} + P_{IL} \times P_{IL,DS} \times P_{DS,TA} , \quad (5.3-8)
 \end{aligned}$$

where

$$\begin{aligned}
 P_{DL,TA} &= P_{DL,TL} + P_{DL,TS} , \\
 P_{DS,TA} &= P_{DS,TL} + P_{DS,TS} .
 \end{aligned}$$

We now assume that

$$P_{IL,TA} = P_{DL,TA} = P_{DS,TA} \equiv P_{A,TA} , \quad (5.3-9)$$

that is, that the probability of surviving the sampling procedure to be classified as live or stunned is the same for live organisms at the intake and for live and stunned organisms in the discharge canal. Thus, we can rewrite Eq. (5.3-8) as

$$\begin{aligned}
 P_{D,TA} &= P_{IL} \times (P_{IL,DL} + P_{IL,DS}) P_{A,TA} \\
 &= P_{IL} \times P_{IL,DA} \times P_{A,TA} , \quad (5.3-10)
 \end{aligned}$$

where

$$P_{IL,DA} = P_{IL,DL} + P_{IL,DS} .$$

Then (rearranging Eq. 5.3-10),

$$P_{IL,DA} = \frac{P_{D,TA}}{P_{IL} \times P_{A,TA}} . \quad (5.3-11)$$

Substituting from Eq. (5.3-7) with $P_{IL,TA} = P_{A,TA}$ from Eq. (5.3-9), we can rewrite Eq. (5.3-11) as

$$P_{IL,DA} = \frac{P_{D,TA}}{P_{I,TA}} . \quad (5.3-12)$$

This is the desired expression (under assumption 2) for $P_{IL,DA}$, the probability of an organism live in the intake being alive (whether "live" or "stunned") in the discharge canal after passage through the plant. In this case, the probability of short-term mortality upon passage through the plant, $f'_{c,s}$ (where the prime symbol indicates assumption 2), is

$$f'_{c,s} = 1 - P_{IL,DA} = 1 - \frac{P_{D,TA}}{P_{I,TA}} = \frac{P_{I,TA} - P_{D,TA}}{P_{I,TA}}. \quad (5.3-13)$$

$P_{I,TA}$ and $P_{D,TA}$ are estimated by calculating the fraction or percentage of organisms classified as either live or stunned from counts of the total number of organisms classified as live, stunned, and dead in intake and discharge-canal samples respectively. This procedure, like the first one, incorporates automatic correction for organisms that are already dead before entering the intake area and for the stunning or mortality of organisms due to the sampling process, if the sampling process is identical with respect to these factors at the intake vs the discharge. Also, like the first procedure, it is sensitive to assumptions about gear avoidance and extrusion.

5.3.5 Current estimates of f_c

5.3.5.1 Consolidated Edison estimates of f_c . In written testimony presented to the Atomic Safety and Licensing Board, Consolidated Edison's staff and consultants presented estimates of entrainment mortality.⁷ The portion of their testimony (as amended) which concerns the cropping factor is quoted below.

E. Entrainment Mortality of Striped Bass

Total entrainment mortality was assumed to be 100% by the Staff and HRFA in the Indian Point 2 hearings (i.e., $f_c = 1.0$). Preliminary NYU studies at Indian Point suggested, however, that some survival could be expected, and in the Indian Point 3 FES, the Staff recognized this (see pp. v. V-215). Literature studies (Marcy, Kerr) suggest survival would vary as a function of several factors, including species, life stage, plant configuration and ambient water temperature.

A substantial body of additional Hudson River data collected during power plant operation now supports Con Edison's position in the 1972-73 Indian Point hearings that f_c for some of the entrainable life stages for striped bass was significantly less than 1.0. Data developed during 1973 and 1974 are reported in the following:

- (1) New York University. 1974. Effects of Entrainment by the Indian Point Power Plant on Biota in the Hudson River Estuary. Progress Report for 1973 to the Consolidated Edison Co. of New York. pp. 226-251.
- (2) New York University. 1976. Effects of Entrainment by the Indian Point Power Plant on Biota in the Hudson River Estuary. Progress Report for 1974 to the Consolidated Edison Co. of New York. pp. 261-281.

- (3) Lawler, Matusky & Skelly Engineers. 1974. 1973
Hudson River Aquatic Ecology Studies - Bowline Point
and Lovett Generating Stations. Vol. III, Chap. IV,
pp. III-7 through III-16. Prepared for Orange and
Rockland Utilities, Inc.
- (4) Lawler, Matusky & Skelly Engineers. 1975. 1974
Hudson River Aquatic Ecology Studies at Bowline and
Lovett Generating Stations, Vol. III, Chap. IX,
pp. IX-15 through IX-17. Prepared for Orange and
Rockland Utilities, Inc.
- (5) Lawler, Matusky & Skelly Engineers. 1974. 1973
Hudson River Aquatic Ecology Studies at Roseton
and Danskammer Point, Vol. II, Chap. V, pp. V-36
through V-39. Prepared for Central Hudson Gas &
Electric Corporation.

All of the NYU data and the 1973 LMS data were obtained using nets in the intake and discharge. In 1974, LMS developed an alternative sampling approach, "the larval table," in an effort to reduce sampling mortality. The purpose of the larval table was to reduce the velocity of water passing through the capture mesh so as not to damage entrained organisms. Preliminary data using this technique were reported by LMS in its 1974 reports.

Work was continued in 1975 and 1976 by NYU at Indian Point and by Ecological Analysts, Inc. (EAI), at Bowline Point and Roseton. EAI used the LMS larval table approach while NYU continued to use nets as specified by the Environmental Technical Specifications Requirements. NYU also conducted flume studies during 1975 in an effort to assess sampling mortality, due to the net sampling at velocities comparable to those found in both the intake forebay and discharge canal at Indian Point. Results of this study indicated that sampling gear could be contributing up to 40% to the estimate of mortality depending on life stage entrained. Results of EAI and NYU studies in 1975 will be contained in the 1977 report. The 1976 data have been collected and are being analyzed. In general, as the techniques of sampling, examination, holding and analysis have improved, mortality due to plant passage has been found to be significantly lower than the 100% originally envisioned by Staff and HRFA. The lower values found in 1975, by comparison with those of 1973 and 1974, are considered to be more complete and more accurate.

This observed entrainment survival is shown in Table [5.3.11]. Values are all based on initial mortalities. Latent mortality results are discussed later. Values are reported alternatively categorizing the stunned organism as

either live or dead. Recent analyses show that if the ratio of stunned to stunned-plus-live is the same in intake and discharge, the categorization of stunned as either live or dead is immaterial; i.e., the resultant calculation for f_c , the entrainment mortality factor, is identical for either case. Further, statistical analysis of the 1975 data on post yolk-sac larvae for all three plants shows no statistically significant difference in this ratio between intake and discharge. The calculated values in Table [5.3.11] show that this observation generally applies to most of the data sets for other years and other stages.

The f_c values for eggs and post yolk-sac larvae and juveniles clearly indicate the entrainment mortality factor is substantially less than unity. The 1974 and 1975 data on eggs show the entrainment initial mortality factor is approximately 0.5. Data indicate that juveniles do not appear in large numbers in the withdrawal zone, and, for the most part, are not vulnerable to entrainment. The few data that do exist show a range in the entrainment mortality factor for early juveniles of 0 to 0.7.

The 1975 data on post yolk-sac larvae are extensive and have been subjected to statistical analysis. No statistically significant difference between intake and discharge survival was found at Bowline Point. Differences at Roseton and Indian Point were found to be statistically significant. Using the mean as the best estimate, the value for the entrainment mortality factor for this stage at Roseton is 0.3 and 0.4 at Indian Point.

The fate of yolk-sac larvae through the plant is unclear. The NYU data, uncorrected for differential net mortality, appear to yield relatively higher values for f_c , ranging from 0.6 to 1.0.

Latent mortality has been studied by NYU and EAI, by holding and observing initially alive and initially stunned organisms for periods up to 96 hours. Most striking is the fact of significant survival after 96 hours, showing clearly that plant-induced mortality is not 100%. Statistical analysis (contingency table analysis) shows no significant difference (with the exception of eggs at Indian Point) in the latent mortality between intake and discharge at all three plants. In fact, even at risk levels ranging from 0.1 to 0.5, no significant differences are detected. Graphical representation of survival versus holding time shows clearly that the mortality rate is virtually identical for intake and discharge, the only difference being due to the difference in initial mortality. Therefore, calculation of f_c using initial mortalities, as in Table [5.3.11], is valid.

Table 5.3.11. [Consolidated Edison's] summary of f_c factors for striped bass^a

Plant	Data source	Eggs	Larvae		Juveniles (JUVENILE I)
			Yolk-sac	Post yolk-sac	
Indian Point	NYU-1973	0.78	0.63 (0.57)	0.52 (0.57)	0.51 (0.69)
	NYU-1974	0.49	0.79 (0.67)	0.38 ^b (0.73)	0.16 (0.68)
	NYU-1975 (preliminary)	0.54	1.00 (1.00)	0.48 (0.45)	0.53 (0.53)
Bowline Point	EAI-1975	<i>c</i>	<i>d</i>	0.09 (0.00)	<i>e</i>
Roseton	EAI-1975	<i>f</i>	0.77 ^g (0.69)	0.25 (0.34)	0.00 ^h (0.00)

^aValues in parentheses represent f_c values computed with stunned organisms considered as dead. Non-parenthesized f_c values were computed with stunned organisms as live. Stunned category not used with eggs. All samples collected with nets except EAI 1975. Net sample f_c uncorrected for differential net mortality. The calculations are all based on initial mortalities.

^bCorrected for differential net mortality between intake and discharge. The uncorrected value is 0.73.

^cNo data available.

^dData limited; only two YS were collected at intake, none in discharge.

^eData limited; only three juveniles collected at discharge, none in intake.

^fData limited; only two dead eggs were collected at intake.

^gData limited; total of five collected at intakes and sixteen at discharge.

^hData limited; four out of seven collected at intake were alive. Three were collected at discharge; two alive and one stunned. Computed $f_c = -0.75$ when stunned considered as live and (-0.17) when considered as dead.

[Source of table: K. P. Campbell et al., "Testimony of Dr. K. Perry Campbell, Dr. John P. Lawler, Dr. Kenneth L. Marcellus, Dr. Mallory S. May, and Dr. James T. McFadden," Testimony before the Atomic Safety and Licensing Board in the Matter of Consolidated Edison Company of New York, Inc., Indian Point Station, Unit No. 2, Docket No. 50-247, OL No. DPR-26, Extension of Interim Operating Period, December 7, 1976, pp. 33-34, as corrected by the authors.]

5.3.5.2 ORNL estimates of f_c . ORNL has calculated, where possible, various estimates of f_c , based on the 1973 and 1974 studies at Indian Point (Sects. 5.3.2 and 5.3.3.1 respectively) and on the 1975 studies at Bowline Point and Roseton (Sects. 5.3.3.2 and 5.3.3.3 respectively). The equations used are those developed in Sect. 5.3.4. Calculations have been done including "live" organisms only (Sect. 5.3.4, assumption 1) and also including both "live" and "stunned" organisms (Sect. 5.3.4, assumption 2). These f_c values represent estimates of the short-term probability of entrainment mortality. In addition, calculations have been made basing $P_{I,TL}$ and $P_{D,TL}$ (for assumption 1 in Sect. 5.3.4) or $P_{I,TA}$ and $P_{D,TL}$ (for assumption 2 in Sect. 5.3.4) on survival at later times as opposed to initial sample survival. This procedure produces estimates that incorporate both short-term mortality and a part of the latent mortality due to entrainment. However, the reliability of these estimates based on later survival is reduced because of smaller sample sizes and the possibility of increased variability occurring from the latent survival holding procedure.

These f_c estimates are shown in Tables 5.3.12, 5.3.13, 5.3.14, and 5.3.15 for striped bass eggs, yolk-sac larvae, post-yolk-sac larvae, and juveniles respectively. No attempt has been made to correct for differential net mortality in the intake vs the discharge at Indian Point based on ref. 6, because results from the types of velocity reduction cones actually used in the discharge area have not been presented separately and because information on velocities in the discharge at times of sampling is not available. The information that is available on these matters would suggest that the true short-term mortality at Indian Point for 1973 and 1974 operating conditions could be less than the estimates shown in Tables 5.3.12-5.3.15. This is by no means certain, however, considering the distinct possibility that mortality increases as organisms move down the discharge canal.

These calculations are based on data that represent only partial power operation. Furthermore, adequate data on life stages other than post-yolk-sac larvae are lacking at Bowline Point and Roseton. Nonetheless, the data taken together suggest that there is some, and perhaps substantial, short- and intermediate-term survival from the direct effects of entrainment. The extent of such survival appears to be plant-specific to some degree; in particular, survival of post-yolk-sac larvae at Bowline under partial power conditions appears to be quite good. The existence of a sampling methodology (pumps discharging into larval tables) that can collect a substantial fraction of organisms alive from intake or discharge areas brings additional hope that immediate and latent entrainment mortality can be determined with reasonable reliability. When such direct mortality appears low, the importance of evaluating the potential for indirect mortality (e.g., via increased susceptibility of entrained organisms to predation) increases.

Table 5.3.12. Estimates of immediate and latent entrainment mortality of striped bass eggs

(Based on live eggs — eggs are not classified as stunned — and, where possible, considering either initial conditions or eventual hatchability.

Immediate entrainment mortality = $f_{c,s}$. It is calculated as:

$$\hat{f}_{c,s} = 1 - \frac{\text{initial fraction alive in discharge samples}}{\text{initial fraction alive in intake samples}},$$

where "alive" may or may not include stunned organisms.

Latent entrainment mortality = $f_{c,l}$. It is calculated as:

$$\hat{f}_{c,l(t)} = 1 - \frac{\text{fraction of total discharge sample remaining alive at } t}{\text{fraction of total intake sample remaining alive at } t},$$

where t is some time after the sample has been taken and "alive" may or may not include stunned organisms)

Basis of calculation	Indian Point		Bowline,	Roseton,
	1973 ^a	1974 ^b	1975 ^c	1975 ^d
Initial conditions	0.73	0.50	e	f
Hatchability	g	0.63	e	f

^a Source of data: New York University, Institute of Environmental Medicine, *Hudson River Ecosystem Studies, Effects of Entrainment by the Indian Point Power Plant on Biota in the Hudson River Estuary, Progress Report for 1973*, prepared for Consolidated Edison Company of New York, Inc., September 1974, Tables 7-3 and 7-4.

^b Source of data: New York University, Institute of Environmental Medicine, *Hudson River Ecosystem Studies, Effects of Entrainment by the Indian Point Power Plant on Biota in the Hudson River Estuary, Progress Report for 1974*, prepared for Consolidated Edison Company of New York, Inc., February 1976, Tables 7-18 and 7-20.

^c Source of data: Ecological Analysts, Inc., *Bowline Point Generating Station, Entrainment Survival and Abundance Studies, Annual Interpretive Report, 1975*, prepared for Orange and Rockland Utilities, Inc., New York, July 1976, vol. 1 and vol. 2.

^d Source of data: Ecological Analysts, Inc., *Roseton Generating Station, Impingement and Entrainment Survival Studies, 1975 Annual Report*, prepared for Central Hudson Gas and Electric Company, New York, December 1976, Table 4.3-1.

^e No organisms collected.

^f Insufficient sample size; too few organisms collected.

^g Not available; data not obtained.

Table 5.3.13. Estimates of immediate and latent entrainment mortality of striped bass yolk-sac larvae

(Based on the use of "live" only or both "live" and "stunned" categories and on initial or latent conditions.

Immediate entrainment mortality = $f_{c,s}$. It is calculated as:

$$\hat{f}_{c,s} = 1 - \frac{\text{initial fraction alive in discharge samples}}{\text{initial fraction alive in intake samples}},$$

where "alive" may or may not include stunned organisms.

Latent entrainment mortality = $f_{c,i}$. It is calculated as:

$$\hat{f}_{c,i}(t) = 1 - \frac{\text{fraction of total discharge sample remaining alive at } t}{\text{fraction of total intake sample remaining alive at } t},$$

where t is some time after the sample has been taken and "alive" may or may not include stunned organisms)

Basis of calculation	Indian Point		Bowline,	Roseton,
	1973 ^a	1974 ^b	1975 ^c	1975 ^d
Live only				
Initial conditions	0.57	(1.0) ^e	<i>f</i>	<i>g</i>
Latent conditions	<i>h</i>	<i>h</i>	<i>h</i>	<i>g</i>
Live plus stunned				
Initial conditions	0.63	0.86	<i>f</i>	(0.77) ^e
Latent conditions	<i>h</i>	<i>h</i>	<i>h</i>	<i>f,g</i>

^aSource of data: New York University, Institute of Environmental Medicine, *Hudson River Power Plant on Biota in the Hudson River Estuary, Progress Report for 1973*, prepared for Consolidated Edison Company of New York, Inc., September 1974, Tables 7-3 and 7-4.

^bSource of data: New York University, Institute of Environmental Medicine, *Hudson River Ecosystem Studies, Effects of Entrainment by the Indian Point Power Plant on Biota in the Hudson River Estuary, Progress Report for 1974*, prepared for Consolidated Edison Company of New York, Inc., February 1976, Tables 7-18.

^cSource of data: Ecological Analysts, Inc., *Bowline Point Generating Station, Entrainment Survival and Abundance Studies, Annual Interpretive Report, 1975*, prepared for Orange and Rockland Utilities, Inc., New York, July 1976, vol. 1, Table 3.3-1.

^dSource of data: Ecological Analysts, Inc., *Roseton Generating Station, Impingement and Entrainment Survival Studies, 1975 Annual Report*, prepared for Central Hudson Gas and Electric Company, New York, December 1976, Table 4.3-2. Calculation is based on reconstruction of numbers from percentages tabulated.

^eEstimate is of highly dubious reliability and fails criteria of (1) at least ten "alive" organisms initially collected at intake, (2) enough organisms collected from discharge that, if survival in discharge sample were same as in intake sample, ten "alive" organisms would have been collected from discharge, and (3) for calculations of latent mortality, at least ten organisms still "alive" in either the intake or the discharge group.

^fInsufficient sample size; too few organisms collected.

^gData needed for calculation exist but have not been reported.

^hNot available; data not obtained.

Table 5.3.14. Estimates of immediate and latent entrainment mortality of striped bass post-yolk-sac larvae

(Based on the use of "live" only or both "live" and "stunned" categories and on initial or latent conditions.

Immediate entrainment mortality = $f_{c,s}$. It is calculated as:

$$\hat{f}_{c,s} = 1 - \frac{\text{initial fraction alive in discharge samples}}{\text{initial fraction alive in intake samples}},$$

where "alive" may or may not include stunned organisms.

Latent entrainment mortality = $f_{c,i}$. It is calculated as:

$$\hat{f}_{c,i(t)} = 1 - \frac{\text{fraction of total discharge sample remaining alive at } t}{\text{fraction of total intake sample remaining alive at } t},$$

where t is some time after the sample has been taken and "alive" may or may not include stunned organisms)

Basis of calculation	<u>Indian Point</u>		Bowline,	Roseton,
	1973 ^a	1974 ^b	1975 ^c	1975 ^d
Live only				
Initial conditions	0.57	0.75	0.0	<i>e</i>
Latent conditions				
24 hr	0.52	0.73	0.09	<i>e</i>
72 hr	0.43	0.65	0.13	<i>e</i>
96 hr	<i>f</i>	<i>f</i>	0.19	<i>e</i>
Live plus stunned				
Initial conditions	0.52	0.76	0.09	0.27
Latent conditions				
24 hr	0.49	0.82	0.11	0.15
72 hr	0.45	0.69	0.17	0.25
96 hr	<i>f</i>	<i>f</i>	0.23	0.63

Table 5.3.14 (continued)

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- ^a Source of data: New York University, Institute of Environmental Medicine, *Hudson River Ecosystem Studies, Effects of Entrainment by the Indian Point Power Plant on Biota in the Hudson River Estuary, Progress Report for 1973*, prepared for Consolidated Edison Company of New York, Inc., September 1974, Tables 7-3, 7-4, and 7-6; Figs. 7-17 and 7-19. Twenty-four-hour values taken from figures in absence of tabulated values; error is possible.
- ^b Source of data: New York University, Institute of Environmental Medicine, *Hudson River Ecosystem Studies, Effects of Entrainment by the Indian Point Power Plant on Biota in the Hudson River Estuary, Progress Report for 1974*, prepared for Consolidated Edison Company of New York, Inc., February 1976, Tables 7-18 and 7-21; Figs. 7-22 and 7-23. Twenty-four-hour values taken from figures in absence of tabulated values; error is possible.
- ^c Source of data: Ecological Analysts, Inc., *Bowline Point Generating Station, Entrainment Survival and Abundance Studies, Annual Interpretive Report, 1975*, prepared for Orange and Rockland Utilities, Inc., New York, July 1976, vol. 1, Table 3.3-2, and vol. 2, Table 3.2.3a. Survival data are given only as fractions; rounding error is possible.
- ^d Source of data: Ecological Analysts, Inc., *Roseton Generating Station, Impingement and Entrainment Survival Studies, 1975 Annual Report*, prepared for Central Hudson Gas and Electric Company, New York, December 1976, Table 4.3-2, Fig. 4.3-1. Twenty-four- and 72-hour values taken from figure in absence of tabulated values; error is possible.
- ^e Data needed for calculation exist but have not been reported.
- ^f Not available; data not obtained.

Table 5.3.15. Estimates of immediate and latent entrainment mortality of striped bass juveniles

(Based on the use of "live" only or both "live" and "stunned" categories and on immediate or latent conditions.

Immediate entrainment mortality = $f_{c,s}$. It is calculated as:

$$\hat{f}_{c,s} = 1 - \frac{\text{initial fraction alive in discharge samples}}{\text{initial fraction alive in intake samples}},$$

where "alive" may or may not include stunned organisms.

Latent entrainment mortality = $f_{c,i}$. It is calculated as:

$$\hat{f}_{c,i(t)} = 1 - \frac{\text{fraction of total discharge sample remaining alive at } t}{\text{fraction of total intake sample remaining alive at } t},$$

where t is some time after the sample has been taken and "alive" may or may not include stunned organisms)

	<u>Indian Point</u>		Bowline,	Roseton,
Basis of calculation	1973 ^a	1974 ^b	1975 ^c	1975 ^d
<hr/>				
Live only				
Initial conditions	0.69	0.68	<i>e</i>	<i>e,f</i>
Latent conditions				
24 hr	0.72	0.69	<i>e</i>	<i>e,f</i>
72 hr	0.77	0.69	<i>e</i>	<i>e,f</i>
96 hr	<i>g</i>	<i>g</i>	<i>e</i>	<i>e,f</i>
Live plus stunned				
Initial conditions	0.51	0.18	<i>e</i>	<i>a</i>
Latent conditions				
24 hr	<i>f</i>	<i>f</i>	<i>e</i>	<i>e</i>
72 hr	<i>f</i>	<i>f</i>	<i>e</i>	<i>e</i>
96 hr	<i>g</i>	<i>g</i>	<i>e</i>	<i>e</i>

Table 5.3.15 (continued)

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- ^a Source of data: New York University, Institute of Environmental Medicine, *Hudson River Ecosystem Studies, Effects of Entrainment by the Indian Point Power Plant on Biota in the Hudson River Estuary, Progress Report for 1973*, prepared for Consolidated Edison Company of New York, Inc., September 1974, Tables 7-3, 7-4, and 7-6; Fig. 7-18. Twenty-four-hour value obtained from figure in absence of tabulated value; error is possible.
- ^b Source of data: New York University, Institute of Environmental Medicine, *Hudson River Ecosystem Studies, Effects of Entrainment by the Indian Point Power Plant on Biota in the Hudson River Estuary, Progress Report for 1974*, prepared for Consolidated Edison Company of New York, Inc., February 1976, Tables 7-18 and 7-21; Fig. 7-24. Twenty-four-hour value obtained from figure in absence of tabulated value; error is possible.
- ^c Source of data: Ecological Analysts, Inc., *Bowline Point Generating Station, Entrainment Survival and Abundance Studies, Annual Interpretive Report, 1975*, prepared for Orange and Rockland Utilities, Inc., New York, July 1976, vol. 1, Table 3.3-1, and vol. 2, Table 3.2.3a. Three juveniles were collected "live" in the discharge. One died within 3 hr, a second within 12 hr, and the third within 48 hr.
- ^d Source of data: Ecological Analysts, Inc., *Roseton Generating Station, Impingement and Entrainment Survival Studies, 1975 Annual Report*, prepared for Central Hudson Gas and Electric Company, New York, December 1976, Table 4.3-2. Four of seven taken at intake were alive and three of three taken at discharge were alive. After 96 hr, one discharge juvenile had died.
- ^e Insufficient sample size; too few organisms collected.
- ^f Data needed for calculation exist but have not been reported.
- ^g Not available; data not obtained.

References for Section 5.3

1. New York University, Institute of Environmental Medicine, *Hudson River Ecosystem Studies, Effects of Entrainment by the Indian Point Power Plant on Biota in the Hudson River Estuary, Progress Report for 1973*, prepared for Consolidated Edison Company of New York, Inc., September 1974.
2. New York University, Institute of Environmental Medicine, *Hudson River Ecosystem Studies, Effects of Entrainment by the Indian Point Power Plant on Biota in the Hudson River Estuary, Progress Report for 1974*, prepared for Consolidated Edison Company of New York, Inc., February 1976.
3. Ecological Analysts, Inc., *Bowline Point Generating Station*, vol. I, 1975 Annual Interpretive Report, Part I: *Entrainment Survival*, Part II: *Ichthyoplankton Entrainment Abundance*, July 1976; vol. II, 1975 Annual Data Report, November 1976; prepared for Orange and Rockland Utilities, Inc., New York, 1976.
4. Ecological Analysts, Inc., *Roseton Generating Station, Impingement and Entrainment Survival Studies, 1975 Annual Report*, prepared for Central Hudson Gas and Electric Company, New York, December 1976.
5. U.S. Nuclear Regulatory Commission, *Final Environmental Statement Related to Operation of Indian Point Nuclear Generating Station, Unit No. 3*, NUREG-75/022, Docket No. 50-286, vols. I and II, February 1975.
6. New York University, Institute of Environmental Medicine, *Mortality of Striped Bass Eggs and Larvae in Nets*, a special report to Consolidated Edison Company of New York, Inc., July 1976.
7. K. P. Campbell et al., "Testimony of Dr. K. Perry Campbell, Dr. John P. Lawler, Dr. Kenneth L. Marcellus, Dr. Mallory S. May, and Dr. James T. McFadden," Testimony before the Atomic Safety and Licensing Board in the Matter of Consolidated Edison Company of New York, Inc., Indian Point Station, Unit No. 2, Docket No. 50-247, OL No. DPR-26, Extension of Interim Operating Period, December 7, 1976, as corrected by the authors.

5.4. Intake f Factor (f_I)

The intake f factor (f_I) is a factor used in young-of-the-year transport models to relate the concentration of ichthyoplankton in the water taken into the plant to the concentration in the river. It is defined for a particular stage as

$$f_I \equiv \frac{C_P}{C_R} ,$$

where C_P is the average concentration of the life stage in water drawn into the plant and C_R is the average concentration of the life stage in the river section (segment) which, in the model, contains the power plant. The term "average" means an average over the period of occurrence of the life stage, considering possible differences between day and night distributions.

5.4.1 Review of information in the IP3 FES

In the IP3 FES, the staff carried out an intensive analysis of existing information relating to intake f factors for various plants. This material is presented in its entirety in Sect. 5.4.1.1 (summary of the analysis as presented in Sect. 5 of the IP3 FES) and Sect. 5.4.1.2 (details of the analysis as presented in Appendix B of the IP3 FES). In excerpting this material, table numbers, figure numbers, reference numbers, and page and section references have been left as they appear in the IP3 FES.

5.4.1.1 Summary of the analysis as presented in Sect. V of the IP3 FES (pp. V-89 through V-101).

(V-89)

(e) Local Spatial Distribution of Striped Bass Eggs, Larvae, and Juveniles

The situation with respect to f factors relating to the local spatial distribution of striped bass eggs, larvae, and juveniles, at the time of the Indian Point Unit No. 2 Hearings, was summarized by the Atomic Safety and Licensing Board⁵⁰ as follows:

"Although there were differences between the Staff and Applicant with regard to the basic models, the really major difference was concerned with the values chosen by the Applicant for the "f" factors, which could be used in either model, and for the effect of compensation. Factor f_1 accounts for a non-uniform distribution of entrainable stages across the river cross section and relates the concentration of organisms in the vicinity of the plant to the average concentration in the river cross section at Indian Point. Factor f_2 is a measure of the susceptibility of organisms to the intake flow expressed as the ratio of the concentration in the intake flow to the concentration in the vicinity of the plant. Factor f_3 accounts for a delay in replacement of organisms removed from the river by the plant. The final factor f_c is the fraction of the organisms that are killed in passing through the plant. Applicant has estimated values for the f factors from the few field

(V-90)

measurements that are available. The product of the chosen values is about 0.4 for eggs and larvae and 0.1 for entrainable juveniles. Use of these factors results in a substantial reduction in the calculated plant impact that HRFA and the Staff argued was not justified by the data. The Board agrees that it is desirable to provide for such effects in a model, that f_c is likely to be less than 1, and that the Applicant has some justification for its best estimate of the combined f factors. Because of the large uncertainties in the data, however, the Board considers the calculations with the combined f factors equal to 1 to be appropriately conservative."

In summary, the controversy over f factors is indicative that all parties realize that (1) the estimated values for these factors have a marked effect on the model predictions of plant impact on the striped bass population and (2) the true values for these factors will have a marked effect on the actual plant impact on the striped bass population. Also, it is obvious that at least f_1 , f_2 , and f_c , unlike compensation, are relatively amenable to estimation from actual data if the proper sampling program is designed and executed.

One of the primary objectives of the applicant's research program for 1973 was to estimate separately for striped bass eggs, yolk-sac larvae, larvae, and juveniles a composite or 24-hour ratio of concentration of organisms in the intakes of the Indian Point Units to the average concentration of organisms in a cross section of the river at Indian Point. (Throughout this Final Statement, the staff denotes this ratio by f_I and refers to a cross section of the river at Indian Point or any other power plant as a transect. The staff's definition of f_I is equivalent to the quotient of the composite "f" over f_c as defined by the applicant, which in turn is approximately equivalent to the product of the applicant's f_1 and f_2 . A discussion of the applicant's f_1 and f_2 is given in Appendix B, Section B.3.h.) The staff has not received these data or an analysis of these data.

Similar, although less comprehensive, sampling programs were designed and executed in 1973 by Quirk, Lawler, and Matusky at the Bowline, Lovett, Danskammer, and Roseton plants. In response to the staff's request, the raw data and the final estimates of a composite "f" factor ($= f_c \cdot f_I$) for each of the four plants for each life stage — striped bass eggs, yolk-sac larvae, post yolk-sac larvae, and juveniles (Table V-13) — were provided. The staff considers these data on the other plants to be crucial in arriving at a sound and accurate assessment of the potential impact of

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Indian Point on the Hudson River striped bass population. [see Sect. V.D.2.d(3)(c)(iii)]

Table V-13. Summary of Quirk, Lawler, and Matusky's composite f factors (1973) with $f_c = 1.0$

Plant	Egg stage ^a	Yolk-sac larval stage	Post yolk-sac larval stage	Juvenile stage
Bowline	0.2	0.1	0.1	0.6
Lovett	0.2	0.2	0.1	0.2
Roseton	0.2	0.1	0.5	0.3
Danskammer	0.2	0.2	0.5	0.3

^aBased on river average observation of striped bass egg behavior surveyed by Texas Instruments in 1973. Since the duration time of the egg stage is approximately 1 to 3 days, the exposure of eggs to entrainment is much smaller than the exposure during the larval stage. Consequently, the f factors for the egg stage are not critical.

Source: Letter from E. R. Fidell (Le Boeuf, Lamb, Leiby, and MacRae) to J. F. Scinto (USAEC), dated August 27, 1974.

The staff has independently analyzed the Quirk, Lawler, and Matusky data. Tables V-14, V-15, and V-16 summarize, by sampling data and life stage for the Bowline, Lovett, and Roseton-Danskammer transects, the number of transect samples, the number of these samples containing one or more striped bass, and the number of these samples containing 10 or more striped bass. Two points deserve mention.

1. No data on striped bass eggs are available for Bowline, Lovett, Roseton, or Danskammer. The egg estimates in Table V-13 are apparently based on Lawler's October 1974 testimony on the effect of entrainment and impingement at Cornwall on the Hudson River striped bass population.¹¹¹
2. The staff contends that a reliable estimate of f_I depends on there being a relatively high number (e.g., ≥ 10) of striped bass ichthyoplankton in the majority of the transect samples during a 24-hr study.

While the data set is of value with respect to indicating the weeks when striped bass ichthyoplankton were present at each of the plants during 1973, the frequent occurrence of zeros in columns B and C of Tables V-14, V-15, and V-16 indicate that most of the sampling effort at each of the

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Table V-14. Tabulation of number of transect samples(A), number of transect samples containing one or more striped bass ichthyoplankters(B), and number of transect samples containing ten or more striped bass ichthyoplankters(C) for each sampling date at Bowline^{a, b}

Date	A	B ₁	B ₂	B ₃	C ₁	C ₂	C ₃
4/10/73	9(6)	0	0	0	0	0	0
5/1/73	4(2)	0	0	0	0	0	0
5/9/73	10(8)	0	0	0	0	0	0
5/23-24/73	76(60)	52(44)	8(7)	0	10(10)	0	0
6/6-7/73	83(43)	33(28)	5(5)	0	6(6)	0	0
6/13-14/73	84(55)	54(38)	49(33)	0	36(24)	32(21)	0
6/20-21/73	74(37)	32(18)	40(20)	4	10(8)	19(10)	0
6/27-28/73	80(46)	41(33)	55(39)	22(15)	14(14)	42(32)	7(4)
7/4-5/73	86(48)	1(1)	26(18)	14(6)	0	4(3)	2(1)
7/10-11/73	91(47)	0	12(9)	8(3)	0	0	0
7/17-18/73	104(56)	0	6(5)	8(2)	0	0	1(0)
7/24-25/73	88(52)	0	0	2(1)	0	0	0
7/31-8/1/73	99(51)	0	0	1(1)	0	0	0
8/7-8/73	113(59)	0	0	0	0	0	0
8/14-15/73	65(34)	0	0	0	0	0	0
8/22-23/73	73(40)	0	0	0	0	0	0
8/30/73	24(14)	0	0	0	0	0	0

^aThe subscripts on the columns headed B and C mean 1 for yolk-sac larvae, 2 for post yolk-sac larvae, and 3 for juveniles.

^bValues not in parentheses are the number of samples taken at the West, Channel, East, Bowline Pond, and Plume sites; values in parentheses are the number of samples taken at the West, Channel, and East sites.

Source: Letter from E. R. Fidell (LeBoeuf, Lamb, Leiby, and MacRae) to M. J. Oestmann (USAEC), dated August 15, 1974.

Table V-15. Tabulation of number of transect samples (A), number of transect samples containing one or more striped bass ichthyoplankters (B), and number of transect samples containing ten or more striped bass ichthyoplankters (C) for each sampling date at Lovett^a

Date	A	B ₁	B ₂	B ₃	C ₁	C ₂	C ₃
4/9/73	20	0	0	0	0	0	0
5/8-9/73	58	5	0	0	0	0	0
5/22-23/73	62	43	10	0	21	0	0
6/5-6/73	75	69	1	0	30	0	0
6/19-20/73	59	48	48	0	30	34	0
7/3-4/73	66	12	46	21	0	5	0
7/18-19/73	111	1	0	0	0	0	0
8/1-2/73	116	0	2	1	0	0	0
8/21-22/73	99	0	0	0	0	0	0

^aThe subscripts on the columns headed B and C mean 1 for yolk-sac larvae, 2 for post yolk-sac larvae, and 3 for juveniles.

Source: Letter from E. R. Fidell (Le Boeuf, Lamb, Leiby, and MacRae) to M. J. Oestmann (USAEC), dated August 15, 1974.

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three transects was wasted for the purposes of estimating f_I for striped bass ichthyoplankton. The juvenile data are particularly weak. In the staff's opinion, the sampling grid and time schedule for sampling were not adequate for estimating f_I . Because the concentration in the Upper West Quadrant at each of these plants is required to estimate both f_1 and f_2 ,¹¹¹ more extensive sampling in that quadrant would have been appropriate, particularly during the approximate four-week period when high concentrations were expected in the transect.

Table V-16. Tabulation of number of transect samples (A), number of transect samples containing one or more striped bass ichthyoplankters (B), and number of transect samples containing ten or more striped bass ichthyoplankters (C) for each sampling date at Roseton-Danskammer^a

Date	A ^b	B	C
3/13/73	2(2)	0	0
3/21/73	4(4)	0	0
4/11/73	8(8)	0	0
5/3/73	2(2)	0	0
5/10-11/73	35(35)	5	0
5/22-23/73	86(78)	17	2
6/7-8/73	68(18)	18	14
6/19-20/73	71(35)	30	8
7/2-3/73	88(46)	12	3
7/17-18/73	86(63)	15	1
7/31-8/1/73	106(103)	9	0
8/14-15/73	69(67)	1	0
8/29-30/73	61(51)	0	0

^aNo distinction was made among yolk-sac larvae, post yolk-sac larvae, and juveniles.

^bValues not in parentheses are the number of transect samples analyzed for total number of ichthyoplankters of all species combined; values in parentheses are the number of these transect samples further analyzed for number of striped bass ichthyoplankters.

Source: Letter from E. R. Fidell (Le Boeuf, Lamb, Leiby, and MacRae) to M. J. Oestmann (USAEC), dated August 15, 1974.

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On the basis of the detailed information summarized in Tables V-14, V-15, and V-16, as well as corresponding data from samples collected at the intakes and discharges of these four plants, the staff estimated f_I for each transect and each life-stage for the two best (i.e., greatest number of samples with striped bass) sampling dates. The data for juveniles at Bowline and Lovett merited analysis on only one date. The estimates are summarized in Table V-17. The details of the staff's analysis are given in Appendix B. While these estimates do not agree exactly with the Quirk, Lawler, and Matusky estimates in Table V-13, they are commonly less than 0.5.

Thus, in summary, the Quirk, Lawler, and Matusky data, as analyzed by the staff using Method B (see Table V-17), suggest that f_I may be less than 0.5 for yolk-sac larvae and post yolk-sac larvae at the other four plants; the data suggest a higher value for juveniles. The staff, however, cannot accept these estimates as accurate representations of reality for the following reasons.

Table V-17. Summary of the staff's estimates of the ratio of intake concentration to transect concentration (f_I) for striped bass yolk-sac larvae (YSL), post yolk-sac larvae (PYSL) and juveniles (JUV) for Bowline, Lovett, Roseton, and Danskammer based on the 1973 QLM data analyzed using Method B^a

Plant	Date	$f_{I,1}^b$			$f_{I,2}^c$		
		YSL	PYSL	JUV	YSL	PYSL	JUV
Bowline	6/13-14	0.90	1.07		0.02	0.04	
	6/27-28	0	0.07	0.74	0	0.07	0.88
Lovett	6/5-6	0.06			0.07		
	6/19-20	0.37	0.09		0.44	0.09	
	7/3-4		0.16	0		0.15	0
Danskammer	6/7-8	0.32			0.27		
	6/19-20		0.89			0.89	
Roseton	7/3-4		13.3			20.5	

^aMethod B (assigning uniform lateral weight as opposed to assigning double weight to midchannel values as in QLM's Method A) was selected by the staff because it is simpler and because QLM's answers using the two methods, except at Cornwall where the 1973 Texas Instruments data are relatively limited, do not differ substantially (i.e., less than 0.1) or systematically. (Testimony of Dr. John P. Lawler, Quirk, Lawler, and Matusky on Effect of Entrainment and Impingement at Cornwall on the Hudson River Striped Bass Population, Federal Power Commission, Project No. 2338, October 1974.)

^bAverage intake and transect concentrations calculated as the average of individual concentrations. See Appendix B for details.

^cAverage intake and transect concentrations calculated as the ratio of the total number collected to the total volume filtered. See Appendix B for details.

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- (1) No information, such as current measurements, thermal measurements, dye studies, or hydrological intake models, has been presented to support the applicant's assumption that the intakes at Bowline, Lovett, Roseton, and Danskammer withdraw 100% of their water from the Upper West Quadrant.
- (2) The sampling methods in the transect and in the intakes differ substantially. No information comparing the relative efficiencies and possible sources of bias of the two methods has been presented.

With respect to the second reservation, the staff has defined the following variables:*

$\bar{x}_I$: the measured average intake concentration over a given period of time.

x_I : the true average intake concentration over the same period.

$\bar{x}_T$: the measured average transect concentration over the same period.

x_T : the true average transect concentration over the same period.

$\bar{x}_S$: the measured average segment concentration over the same period.

x_S : the true average segment concentration over the same period.

Let

$$K_I = \bar{x}_I/x_I; \quad K_T = \bar{x}_T/x_T; \quad K_S = \bar{x}_S/x_S,$$

* The term transect refers to a cross section of the river taken in front of a power plant, that has a longitudinal dimension of less than one mile. The term segment refers to a reach of the Hudson River specified in either the staff's or the applicant's striped bass model. In those segments containing a power plant, the segment encompasses the corresponding transect. The longitudinal dimension of a segment is two miles in the staff's model and ten miles in the applicant's model.

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and let $\hat{f}_I = \bar{x}_I / \bar{x}_T$; $f_I = x_I / x_T$

$$\hat{f}_T = \bar{x}_T / \bar{x}_S; f_T = x_T / x_S$$

The caret over an f denotes an estimate as opposed to the true parameter.

Quirk, Lawler, and Matusky (QLM) is assuming that $\hat{f}_I \approx f_I$ (i.e., that $K_I = K_T$). In fact, K_I , K_T , x_I , and x_T are unknown. Moreover, there is reason to believe that $K_I < K_T$, which would result in $\hat{f}_I < 1.0$, even if $x_I = x_T$ and $f_I = 1.0$. At the intakes QLM used a fixed 1/2-m Hensen net; the approximate intake velocities were 0.2 to 0.3 fps at Bowline, 0.8 fps at Lovett, 0.5 to 0.7 fps at Roseton, and 0.8 fps at Danskammer.

In the transects QLM towed a 1-m Hensen net at a velocity of 2.6 to 3.0 fps. The difference in efficiency at a series of velocities of a 1/2-m net containing a flow meter and fixed in a rack and a 1-m net without an internal flow meter and towed behind a boat clearly should have been evaluated, but apparently it was not. To assume equal efficiencies even at a common velocity is not technically sound for reasons discussed in Sect. V.D.2.e. To assume equal efficiencies at velocities of less than 1.0 fps (as at the intakes) and approximately 3.0 fps (as in the transect sampling) is even less technically sound. Although the staff is not aware of any data for striped bass ichthyoplankton relating estimated concentration to towing speed, size, or type of net, it is reasonable to define a new f -factor, f_v , as the ratio of the concentration obtained at the towing speed used in the transect or segment with a 1-m net to the concentration obtained at a towing speed that corresponds to the intake velocity with a 0.5-m net rigged as much as possible like the 0.5-m fixed nets at the intakes. In general, estimates of concentration of mobile ichthyoplankton increase with increasing tow speed or, more generally, with increasing velocity of the water being sampled relative to the sampling net.^{51,52} Also, estimates of concentration increase with increasing size of the net, provided adequate velocity relative to the water can be maintained.⁵³ The point is that f_v may well be greater than 1.0 for post yolk-sac larvae and juveniles. For eggs and yolk-sac larvae, f_v could be less than 1.0 due to loss of organisms in the net at high velocities. Information necessary to estimate f_v is essential before estimates of f_I should be considered accurate.

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As discussed in Appendix B, QLM has completely ignored the f factor relating transect concentrations to river segment concentrations (f_T). The transect concentrations generally are based on data from 5-min, longitudinal tows in the river opposite the plants at a speed of approximately 2.8 fps; thus, transect concentrations are representative of a volume having a longitudinal dimension of less than a quarter of a mile (2.8 fps for 5 min = 0.16 miles $\cong$ 300 yds). The QLM segment concentrations are representative of a volume having a longitudinal dimension of 10 miles in their model. From a conceptual and mathematical point of view, f_T must be included in the model formulation; QLM has implicitly assumed that $f_T = 1.0$.

The factor f_T is also worth considering from the point of view of sampling efficiencies, because data are available to estimate both transect and segment concentrations. The average weekly segment concentration ($\bar{x}_S$) for yolk-sac larvae, post yolk-sac larvae, and juveniles for each of the sampling dates used in the staff's estimation of f_I (Table V-17) are given in Table V-18 for the QLM river segments containing Bowline, Lovett, Roseton, and Danskammer. The 24-hr average transect concentrations ($\bar{x}_T$) and intake concentrations ($\bar{x}_I$) also are given in Table V-18 calculated by using both Methods 1 and 2 (i.e., average of the individual concentrations versus the ratio of the average number collected to the average volume sampled).*

The staff's opinion is that on the average $x_T \cong x_S$; that is, the true average transect concentration over a period of time will approximately equal the true average river segment concentration over the same period. Thus, when the corresponding measured concentrations quite consistently indicate that $\hat{x}_T > \hat{x}_S$, one can logically assume that $K_T > K_S$ due to differences in sampling efficiencies. The transect samples are collected using 1-m Hensen nets and a tow speed of 2.6 to 3.0 fps. The segment samples are collected using an epibenthic sled and Tucker trawl with tow speeds of approximately 2.6 fps for the sled and 4.9 fps with the trawl.⁵⁴ The 1973 QLM and Texas Instruments (TI) data strongly suggest that the QLM transect sampling was consistently more efficient than the TI segment sampling. Why this should be so is not apparent to the staff since the sampling equipment and tow speeds do not appear to differ inordinately, and most of the differences would tend to bias the TI data to the high side rather than the low side, at least for older stages. An alternative

*The staff's Methods 1 and 2 for calculating concentration of organisms in a sample which are defined above, should not be confused with the applicant's Methods A and B for calculating f_I .¹¹¹

Table V-18. Weekly segment concentration, 24-hr transect concentration, 24-hr intake concentration, and the staff's alternative estimate of the intake factor
(all concentrations have units of number of organisms per 1000 cubic meters)

Values are given using Methods 1 and 2 (See Appendix B, Section B.3) for striped bass yolk-sac larvae (YSL), post yolk-sac larvae (PYSL), and juveniles (JUV) for Bowline, Lovett, Roseton, and Danskammer based on the 1973 QLM transect and intake data and the QLM reduction of the 1973 TI river-segment data.

Plant	Date	Method 1												Method 2											
		$\bar{X}_S^a$			$\bar{X}_{T,1}^b$			$\bar{X}_{1,1}^c$			$\hat{f}_{1,1}^d$			$\bar{X}_S^a$			$\bar{X}_{T,2}^e$			$\bar{X}_{1,2}^f$			$\hat{f}_{1,2}^g$		
		YSL	PYSL	JUV	YSL	PYSL	JUV	YSL	PYSL	JUV	YSL	PYSL	JUV	YSL	PYSL	JUV	YSL	PYSL	JUV	YSL	PYSL	JUV	YSL	PYSL	JUV
Bowline	6/13-14	29.7	110.2		154.5	198.0		138.9	211.0		4.68	1.92		29.7	110.2		148.8	184.4		2.53	6.93		0.09	0.07	
	6/27-28	0	128.6	0	121.8	474.9	11.8	0	33.8	8.78	0	0.26	8.78	0	128.6	0	107.6	426.5	10.9	0	28.3	9.09	0	0.22	9.63
Lovett	6/5-6	7.7			105.3			6.25			0.81			7.7			100.8			7.16			0.86		
	6/19-20	0	26.4		146.8	418.6		54.8	36.3		54.8	1.38		0	26.4		136.9	399.1		61.3	35.4		60.0	1.36	
	7/3-4		13.7	5.2		29.2	3.73		4.63	0		0.34	0		13.7	5.2		27.6	3.45		4.91	0		0.30	0
Danskammer	6/7-8	113.3			598.9			193.2			0.77			113.3			586.1			177.2			0.80		
	6/19-23		29.6			35.6			31.9			1.08			29.6			36.5			32.5			1.10	
Roseton	7/2-3		30.1			7.20			96.0			3.19			30.1			4.72			81.3			3.21	

^aWeekly segment concentration as calculated from the number of organisms and volume data from QLM's reduction of the 1973 TI river data. Letter from Carl L. Newman, Vice President, Consolidated Edison Company of New York, Inc., to George W. Knighton, Chief, Environmental Projects Branch No. 1, Directorate of Licensing, U.S. Atomic Energy Commission, dated August 30, 1974.

^bTwenty-four hour average transect concentration calculated using the individual concentrations.

^cTwenty-four hour average intake concentration calculated using the individual concentrations.

^d $\hat{f}_{1,1} = \bar{f}_y (\bar{X}_{1,1} / \bar{X}_S)$. The staff has used $\bar{f}_y = 1.0$ for all stages, although there is reason to believe that $\bar{f}_y$ exceeds 1.0 for post yolk-sac larvae and juveniles.

^eTwenty-four hour average transect concentration calculated using the average of the number of organisms in the samples and the average volume of water sampled.

^fTwenty-four hour average intake concentration calculated using the average of the number of organisms in the samples and the average volume of water sampled.

^g $\hat{f}_{1,2} = \bar{f}_y (\bar{X}_{1,2} / \bar{X}_S)$. The staff has used $\bar{f}_y = 1.0$ for all stages, although there is reason to believe that $\bar{f}_y$ exceeds 1.0 for post yolk-sac larvae and juveniles.

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explanation for the consistent and considerable differences between the QLM transect concentrations and the TI segment concentrations would be systematic inconsistencies between QLM and TI in distinguishing between striped bass and white perch such that QLM identified more *Morone* sp. as striped bass.

Having established that K_T is consistently and considerably greater than K_S , it is of paramount concern to know if K_I is closer to K_T or K_S . If $K_I \cong K_T$, the $\hat{f}_I$ values in Table V-17 may be appropriate. If $K_I \cong K_S$, the staff's alternate $\hat{f}_I^*$ values in Table V-18 may be appropriate; the alternate intake f factors are commonly greater than 1.0.

In the face of the considerable uncertainty concerning f factors, the values of which have a dramatic effect on the model predictions of the impact of Indian Point operation on the striped bass population, the staff has done an extensive parametric study for f_I using the staff's new y-o-y striped bass model. Fig. V-11 is a graph of predicted percentage reduction in y-o-y striped bass versus f_I over the range for f_I of 0.0 to 2.0. A f_I value of 0.2 as compared to 1.0 decreases the predicted percentage reduction in number of y-o-y striped bass surviving the first 20 weeks of life due to the operation of Indian Point Units Nos. 1, 2, and 3 with once-through cooling from approximately 36% to 14%.

The staff's best judgment concerning the value of f_I is that the data and analyses currently available, including the staff's analysis as given in this section and in App. B, Sections B.3 and B.4.b(3)(b)(1), support an f_I value of less than 1.0 for yolk-sac larvae, post yolk-sac larvae, and juveniles at Bowline, Lovett, Roseton, and Danskammer. Furthermore, the staff believes that it is safe to extrapolate this judgment to include striped bass eggs and to include all four life stages at Indian Point. This extrapolation is based in part on the staff's results from the new young-of-the-year model.

To achieve reasonable verifications of the staff's model based on 1973 data, it was necessary to use relatively high values of the convective transport defect factor [see App. B, Section B.4.b(5)(b)] for the early life stages (eggs, yolk-sac larvae, and post yolk-sac larvae), indicating that significant vertical and/or lateral variations in the distribution of the age group populations do indeed exist in the estuary, with high concentrations occurring near the bottom or near the shores. These variations result in the retardation of the convective downstream motion of the populations by the net freshwater flow. Hence, from considerations of consistency in modeling as well as from indications in the

Fig. V-11. Predicted percentage reduction in number of y-o-y striped bass surviving the first 20 weeks of life due to the operation of Indian Point Units Nos. 1, 2, and 3 with once-through cooling as a function of the intake f-factor, f_I . The baseline used for calculation of percentage reduction values was conditions in 1973 (i.e., all units at Lovett and Danskammer and Unit No. 1 at Bowline).

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1973 data, it is realistic to accept that the f_I values can indeed be, and likely are, less than unity. However, due caution must be exercised in the estimation of the values for the intake density ratio, and the above conclusion by no means implies that the extremely low values for the intake f factors suggested recently by the applicant (Table V-13) are realistic and acceptable for the assessment of the entrainment and impingement impact.

Because there is considerable uncertainty in the available data and because the value of f_I has a marked effect on forecasts of percent reduction by the staff's y-o-y model, the staff has done each run of the model using values of 0.5 and 1.0 for f_I . Results are presented in Sect. V.D.2.d(3)(c)(iii).

The staff's opinion is that the data are too limited and too variable to specify a single best estimate. Rather, the staff's best judgment is that for all life stages at all plants, f_I is probably less than 1.0 but not less than 0.5.

REFERENCES FOR SECTION 5.4.1.1
(from excerpted material in IP3 FES)

50. Atomic Safety and Licensing Board, "In the Matter of Consolidated Edison Company of New York, Inc., (Indian Point Station, Unit No. 2), Docket No. 50-247, Initial Decision (LBP-73-33), September 25, 1973," in *Regulatory Adjudicatory Issuances*, vol. 73-9, pp. 151-92 (1973).
51. W. Aron and S. Collard, "A Study of the Influence of Net Speed on Catch," *Limnol. Oceanogr.* 14(2): 242-49 (1969).
52. R. L. Noble, "Evaluation of the Miller High-Speed Sampler for Sampling Yellow Perch and Walleye Fry," *J. Fish. Res. Bd. Can.* 27: 1033-44 (1970).
53. R. I. Clutter and M. Anraku, "Avoidance of Samplers," *Monogr. Oceanogr. Methodology* 2: 57-76 (1968).
54. Texas Instruments, Inc., Services Group, *Fisheries Survey of the Hudson River, March-December 1973*, vol. IV (draft), prepared for the Consolidated Edison Company of New York, Inc., September 1974.
111. Testimony of John P. Lawler, Partner, Quirk, Lavler, and Matusky Engineers, "Effect of Entrainment and Impingement at Cornwall on the Hudson River Striped Bass Population," before the United States of America, Federal Power Commission, in the Matter of Consolidated Edison Company of New York, Inc., Project No. 2338 (Cornwall), October 1974.

5.4.1.2 Details of the analysis as presented in Appendix B of the IP3 FES (pp. B-29 through B-52).

(B-29)

3. LOCAL SPATIAL DISTRIBUTION OF STRIPED BASS ICHTHYOPLANKTON

As discussed in Section V.D.2.b(2)(e), sampling programs were designed and executed in 1973 by Quirk, Lawler, and Matusky at the Bowline, Lovett, Danskammer, and Roseton Plants to estimate, for striped bass yolk-sac larvae, post yolk-sac larvae, and non-screenable juveniles, the ratio of concentration of organisms in the intake to the average concentration of organisms in a cross section of the river in front of the plant (= transect). In response to the staff's request, the raw data and final estimates of a composite "f" factor ($= f_c \cdot f_I$) for each life stage at each plant were provided (Table B-16).

The staff has done its own analysis of the Quirk, Lawler, and Matusky data. Part of this analysis is given in Section V.D.2.b(2)(e), where the staff has summarized, by sampling date and life stage for each of the three transects (the same transect was used for Danskammer and Roseton), the number of transect samples, the number of these samples containing one or more striped bass, and the number of these samples containing 10 or more striped bass; this part of the analysis is not repeated here. On the basis of this analysis, however, the staff selected for each transect and each life stage the two sampling dates having the greatest number of samples containing striped bass; this section of Appendix B deals with the analysis of these data.

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Table B-16. Summary of Quirk, Lawler, and Matusky's estimates of composition
f factors (1973) with $f_c = 1.0$

Plant	Egg stage ^a	Yolk-sac larval stage	Post yolk-sac larval stage	Juvenile stage
Bowline	0.2	0.1	0.1	0.6
Lovett	0.2	0.2	0.1	0.2
Roseton	0.2	0.1	0.5	0.3
Danskammer	0.2	0.2	0.5	0.3

^aBased on river average observation of striped bass egg behavior surveyed by Texas Instruments in 1973. Since the duration time of the egg stage is approximately 1 to 3 days, the exposure of eggs to entrainment is much smaller than the exposure during the larval stage. Consequently, the f factors for the egg stage are not critical.

Source: Letter from E. R. Fidell (Le Boeuf, Lamb, Leiby, and MacRae) to J. F. Scinto (USAEC), dated August 27, 1974.

The analysis is divided into the following sections: (1) correlations between number of organisms in a sample and volume of water sampled; (2) estimates of the intake f-factor (f_I), using four techniques based on two methods of estimating 24-hr average intake and transect concentrations; (3) estimates of a standard deviation for f_I ; (4) a comparison of intake and discharge concentrations; and (5) a separate analysis comparing Bowline Pond and Bowline transect data.

a. Correlation Coefficients

The (product-moment) correlation coefficient was calculated between number of yolk-sac larvae in a sample and volume of the sample and between number of post yolk-sac larvae and volume of the sample for each of the sampling dates at each of the plants; the results of this analysis are summarized in Table B-17. Juveniles have not been included in this part of the staff's analysis because of the relatively few samples containing juveniles. The analysis indicates the absence of a statistically significant (at the 5% level) correlation in 9 out of 10 cases. This result is most easily explained by the existence of patchiness (clumping) in the spatial distribution of organisms and/or by vertical migration. One apparent example of such patchiness is the 12 intake samples at Bowline on June 13-14. There were eleven 2-hr samples containing no yolk-sac larvae and a total of four post yolk-sac larvae and one 2-min sample containing two yolk-sac larvae and three post yolk-sac larvae.

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Table B-17. Summary of the (product moment) correlation coefficients between the number of yolk-sac larvae and volume of the sample and between the number of post yolk-sac larvae and volume of the sample for each sampling date at each of the plants

Plant ^a	Date	Yolk-sac larvae		Post yolk-sac larvae	
		N ^b	r	N ^b	r
Bowline	6/13-14	84	-0.15	84	-0.14
	6/27-28	75	0.08	75	0.12
Lovett	6/5-6	94	0.10		
	6/19-20	74	0.10	74	0.14
	7/3-4			84	0.11
Danskammer-Roseton ^c	6/7-8	41	0.18		
	6/19-20			54	0.31 ^d
	7/2-3			67	-0.10

^aFor this analysis, the intake and transect samples at each plant were combined. Discharge samples were deleted; pond and plume samples at Bowline were deleted; and mid-depth samples were not given double weight.

^bTotal number of samples.

^cOn June 7-8 and June 19-20 the Danskammer-Roseton transect data were combined with the Danskammer intake data. On July 2-3 the transect data were combined with the Roseton intake data. There was no second sampling date at the Roseton intake for which enough striped bass were identified to merit analysis; samples were not collected on June 19-20 and only one of five samples on June 7-8 was analyzed by species.

^dStatistically significant at the 0.05 probability level.

b. Estimates of the Intake f-Factor (f_I)

The staff has estimated f_I using four techniques based on two methods of estimating the 24-hr average intake and transect concentrations. The f_I values, as well as the information necessary to calculate these f_I values, are given in Table B-19. Definitions of the acronyms used in this table and in Table B-21 are given in Table B-18. The values in Table B-19 were calculated from the raw data supplied to the staff by the applicant.¹⁸ The staff repeats that this analysis includes data for only the two "best" sampling dates for each life stage and each plant. In some cases (e.g., for juveniles), there were not two sampling dates having enough samples with striped bass to merit analysis by the staff. Discharge samples have not been included in this part of the staff's analysis.

The two methods of estimating the 24-hr average concentrations at either the intake or in the transect are:

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Table B-18. Glossary of acronyms used in Tables B-19 and B-21

Variable	Definition			
	Code number	Plant		
		Bowline	Lovett	Danskammer - Roseton
Part A. Classification variables				
Date	1	6/13-14	6/5-6	6/7-8 (Danskammer)
	2	6/27-28	6/19-20	6/19-20 (Danskammer)
	3		7/3-4	7/2-3 (Roseton)
Plant	<i>Code number</i>	<i>Plant</i>		
	1	Bowline		
	2	Lovett		
	3	Danskammer - Roseton		
Stage	<i>Code number</i>	<i>Stage</i>		
	1	Yolk-sac larvae		
	2	Post yolk-sac larvae		
	3	Juveniles		
OBS	Row number in Tables B-19 and B-21. Each row gives the variables at one plant on one date for one life stage.			

Part B. Calculated variables. The acronyms indicate whether the variable relates to an intake (I) or transect (T) sample and to a night (N) or day (D) sample.

Variable	Definition
<i>Technique 1</i>	
FI1	Ratio of the 24-hr average intake concentration to the 24-hr average transect concentration using Method 1 to calculate both concentrations.
<i>Technique 2</i>	
FI2	Ratio of the 24-hr average intake concentration to the 24-hr average transect concentration using Method 2 to calculate both concentrations.
<i>Technique 3</i>	
FI3	Ratio of the 24-hr average intake concentration to the 24-hr average transect concentration using Method 2 to calculate the intake concentration and Method 1 to calculate the transect concentration.
<i>Technique 4</i>	
FI4	Ratio of the 24-hr average intake concentration to the 24-hr average transect concentration using Method 1 to calculate the intake concentration and Method 2 to calculate the transect concentration.
NID	Number of intake samples during the day (= 0600 to 2100).
NIN	Number of intake samples during the night (= 2101 to 0600).
NTD	Number of transect samples during the day.
NTN	Number of transect samples during the night.
SDXID	Standard deviation of the intake day concentrations (number of organisms/1000 m ³).
SDXIN	Standard deviation of the intake night concentrations (number of organisms/1000 m ³).

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Table B-18 (continued)

SDXTD	Standard deviation of the transect day concentrations (number of organisms/1000 m ³).
SDXTN	Standard deviation of the transect night concentrations (number of organisms/1000 m ³).
SDYID	Standard deviation of the intake day number-of-organism values.
SDYIN	Standard deviation of the intake night number-of-organism values.
SDYTD	Standard deviation of the transect day number-of-organism values.
SDYTN	Standard deviation of the transect night number-of-organism values.
SDZID	Standard deviation of the intake day volumes (1000 m ³).
SDZIN	Standard deviation of the intake night volumes (1000 m ³).
SDZTD	Standard deviation of the transect day volumes (1000 m ³).
SDZTN	Standard deviation of the transect night volumes (1000 m ³).
TSDFI1	Two times the standard deviation of $f_{I,1}$.
TSDFI2	Two times the standard deviation of $f_{I,2}$.
XID	Average of the intake day concentrations (number of organisms/1000 m ³).
XIN	Average of the intake night concentrations (number of organisms/1000 m ³).
XTD	Average of the transect day concentrations (number of organisms/1000 m ³).
XTN	Average of the transect night concentrations (number of organisms/1000 m ³).
YID	Average of the intake day number-of-organism values.
YIN	Average of the intake night number-of-organism values.
YTD	Average of the transect day number-of-organism values.
YTN	Average of the transect night number-of-organism values.
ZID	Average of the intake day volumes (1000 m ³).
ZIN	Average of the intake night volumes (1000 m ³).
ZTD	Average of the transect day volumes (1000 m ³).
ZTN	Average of the transect night volumes (1000 m ³).

Table B-19. Sample size, mean and standard deviation for night and day, intake and transect values for number of organisms, volume of sample, and concentration. Also tabulated (on the next page) are intake f factor values (f_1), calculated using four techniques, and approximate 95% confidence intervals for $f_{1,1}$ and $f_{1,2}$. Values are given for yolk-sac larvae, post yolk-sac larvae, and juveniles at Bowline, Lovett, and Darskammer-Eoseton. Acronyms are defined in Table B-18.

The lower half of this page is a continuation of the upper half. The next page is a further continuation of the table and contains the footnotes; see numbers in "OBS" column.

OBS	PLANT ^a	DATE	STAGE	NIN	YIN	SDYIN	XIN	SEXIN	XIN	SDXIN	NID	YID	SDYID	ZID	SDZID	XIC
1	1	1	1	11	0.000	0.000	.1270	.0000	0.00	0.00	9	0.444	0.881	.0992	.0551	222.20
2	1	1	2	11	0.545	1.210	.1270	.0000	4.29	9.56	9	0.889	1.269	.0992	.0551	335.10
3	1	2	1	8	0.000	0.000	.0146	.0039	0.00	0.00	20	0.000	0.000	.0160	.0000	0.00
4	1	2	2	8	0.500	0.756	.0146	.0039	48.40	76.30	20	0.400	0.395	.0160	.0000	25.00
5	1	2	3	8	0.375	0.744	.0146	.0039	23.40	46.50	20	0.000	0.000	.0160	.0000	0.00
6	2	1	1	12	0.500	0.798	.0640	.0635	6.75	13.90	8	0.125	0.354	.0210	.0000	5.95
7	2	2	1	7	1.570	3.050	.0321	.0160	34.90	67.70	8	3.000	3.510	.0450	.0000	66.70
8	2	2	2	7	1.290	1.600	.0321	.0160	41.30	39.40	8	1.500	1.600	.0450	.0000	33.30
9	2	3	2	7	0.000	0.000	.0150	.0000	0.00	0.00	12	0.167	0.389	.0250	.0148	7.41
10	2	3	3	7	0.000	0.000	.0150	.0000	0.00	0.00	12	0.000	0.000	.0250	.0148	0.00
11	3	1	1	12	24.750	22.030	.1030	.0726	233.60	147.30	8	6.125	7.920	.0566	.0457	168.90
12	3	2	2	6	0.833	1.330	.1010	.0779	4.14	6.61	12	4.750	6.540	.1010	.0742	48.50
13	3	3	2	12	0.750	1.360	.0222	.0137	44.40	78.50	10	1.600	2.880	.0119	.0052	127.00
OBS	SDYID	NTN	YTN	SDYTN	XTN	SDXTN	XTN	SDXTN	NTD	YTD	SDYTD	ZTD	SDZTD	XTD	SDXTD	
1	441.0	20	36.850	28.400	.162	.0271	123.70	156.10	56	20.140	33.700	.166	.0188	129.800	214.90	
2	660.5	20	52.000	39.640	.162	.0271	313.50	215.70	56	22.710	50.500	.166	.0188	156.700	369.10	
3	0.0	15	7.070	12.940	.180	.0280	37.10	59.50	41	23.660	46.840	.178	.0295	152.800	317.30	
4	62.2	15	66.870	66.190	.180	.0280	396.50	417.10	41	79.540	133.940	.178	.0295	503.600	904.10	
5	0.0	15	3.670	6.260	.180	.0280	21.70	39.70	41	1.320	5.400	.178	.0295	8.190	34.40	
6	16.8	37	14.050	18.890	.163	.0371	95.50	134.20	64	18.500	26.540	.170	.0294	111.000	148.60	
7	77.9	31	28.870	30.960	.157	.0223	203.50	235.50	49	17.240	27.610	.160	.0246	111.000	179.20	
8	35.6	31	73.290	74.460	.157	.0223	498.30	518.90	49	57.140	102.010	.160	.0246	368.100	634.60	
9	19.7	35	2.200	1.680	.165	.0343	13.40	9.45	56	6.040	12.920	.166	.0373	39.100	82.20	
10	0.0	35	0.429	0.608	.165	.0343	2.84	4.06	56	0.661	1.080	.166	.0373	4.280	6.81	
11	222.0	32	107.840	121.130	.184	.0181	598.90	671.80	0	0.000	0.000	.000	.0000	0.000	0.00	
12	62.3	20	8.050	11.040	.181	.0234	41.00	54.90	34	6.260	7.890	.195	.0307	32.500	40.40	
13	171.1	24	2.830	4.750	.211	.0912	20.90	40.60	53	0.170	0.509	.212	.1760	0.999	2.88	

Table B-19 (continued)

OBS	PLANT	DATE	STAGE	FI 1	TSDFI 1	FI 2	TSDFI 2	FI 3	FI 4
1	1	1	1	0.8988	1.2191	0.0188	0.0376	0.9336	0.0181
2	1	1	2	1.0661	1.4508	0.0391	0.0814	1.1444	0.0364
3	1	2	1	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
4	1	2	2	0.0711	0.0647	0.0667	0.1478	0.0792	0.0599
5	1	2	3	0.7431	1.2061	0.8821	3.0011	0.8036	0.8157
6	2	1	1	0.0593	0.0777	0.0660	0.1456	0.0620	0.0631
7	2	2	1	0.3730	0.2921	0.4383	0.9614	0.4001	0.4087
8	2	2	2	0.0867	0.0537	0.0900	0.1946	0.0909	0.0858
9	2	3	2	0.1585	0.2542	0.1515	0.3031	0.1681	0.1429
10	2	3	3	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
11	3	1	1	0.3225	0.2146	0.2691	0.5728	0.3296	0.2634
12	3	2	2	0.8939	0.7076	0.8907	1.7974	0.8737	0.9113
13	3	3	2	13.3333	13.6475	20.4894	41.4747	20.3459	13.4273

^aBowline Plume and Pond samples deleted; discharge samples at all plants deleted; and mid-depth samples both at the intakes and in the transects given double weight (i.e., QLM's Method B). None of the June 7-8 transect day samples at Danskammer-Roseton were analyzed for striped bass. June 7-8 and June 19-20 Danskammer-Roseton transect data were combined with Danskammer intake data. July 2-3 transect data were combined with Roseton intake data. There was no second sampling date at Roseton for which enough striped bass were identified to merit analysis by the staff. The TI 1973 ichthyoplankton data indicated that the "larvae" collected at Danskammer-Roseton on June 7-8 were probably all yolk-sac larvae, that those collected on June 19-20 were probably all post yolk-sac larvae, and that those collected on July 2-3 were probably mostly post yolk-sac larvae.

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(1) Method 1: for each sample calculate a concentration as the ratio of the number of organisms in the sample to the volume of water filtered, and then calculate the average of the individual concentrations over the 24-hr period,

(2) Method 2: calculate the 24-hr average number of organisms in a sample and the 24-hr average volume of water filtered, and then take the ratio of these two 24-hr averages.

The four techniques of combining these two methods to estimate f_I are defined in Table B-18.

The values in Table B-19 indicate that the manner in which these two methods are combined can have a pronounced effect on the estimate of f_I . For instance, in the second row of Table B-19, at Bowline on June 13-14, 1973, for post yolk-sac larvae, $f_{I,1} = 1.07$ and $f_{I,3} = 1.14$, while $f_{I,2} = 0.04$ and $f_{I,4} = 0.04$; the Quirk, Lawler, and Matusky technique of estimating f_I corresponds to $f_{I,4}$.^{*} Although other differences are less pronounced, the staff's analysis does make clear that, disregarding problems with sampling design and sampling techniques, the technique of calculation alone has an influence on the estimate of f_I .

The staff's best judgment is that either technique 1 or 2 is preferable to technique 3 or 4. The staff offers no justification in mixing apples and prunes by calculating 24-hr average intake concentrations with one method and 24-hr average transect concentrations with a second method, and the staff considers that such an approach is not statistically acceptable. The choice between technique 1 and 2 ($f_{I,1}$ and $f_{I,2}$) is not clear cut, although technique 2 is the more commonly used and accepted approach.¹⁹

c. Estimates of Standard Deviations for the Intake f-Factor (f_I)

The staff has estimated the standard deviation of $f_{I,1}$ and $f_{I,2}$ as follows (acronyms are defined in Table B-18):

* This difference and the one for yolk-sac larvae at Bowline on the same date are due to the "unusual" (patchy) intake samples mentioned previously (viz., eleven 2-hr samples containing no yolk-sac larvae and four post yolk-sac larvae and one 2-min sample containing two yolk-sac larvae and three post yolk-sac larvae).

(B-39)

$$(1) \quad FII (= f_{I,1})$$

$$FII = (0.375 \text{ XIN} + 0.625 \text{ XID})/\text{XT24} \quad (1)$$

where

$$\text{XT24} = (\text{NTN} \cdot \text{XTN} + \text{NTD} \cdot \text{XTD})/(\text{NTN} + \text{NTD}) \quad (2)$$

Variance of the ratio of two random variables, Y and Z, may be approximated by the following expression:

$$\text{Var}(Y/Z) \approx \left(\frac{Y}{Z}\right)^2 \left[\frac{\text{Var}(Y)}{Y^2} + \frac{\text{Var}(Z)}{Z^2} - \frac{2 \text{Cov}(Y,Z)}{YZ} \right] \quad (3)$$

In the present application $Y = 0.375 \text{ XIN} + 0.625 \text{ XID}$, $Z = \text{XT24}$, and $\text{Cov}(Y,Z) = 0$ since the intake and transect samples used to calculate the concentrations are assumed to be statistically independent. It is also assumed that night and day intake or transect samples are statistically independent, i.e., $\text{Cov}(\text{XIN}, \text{XID}) = 0$ and $\text{Cov}(\text{XTN}, \text{XTD}) = 0$.

Thus,

$$\text{Var}(FII) = (FII)^2 \left[\frac{0.375^2 \text{Var}(\text{XIN}) + 0.625^2 \text{Var}(\text{XID})}{(0.375 \text{ XIN} + 0.625 \text{ XID})^2} + \frac{\text{Var}(\text{XT24})}{\text{XT24}^2} \right] \quad (4)$$

$$\text{Var}(\text{XIN}) = \text{SDXIN}^2/\text{NIN} \quad (5)$$

and

$$\text{Var}(\text{XID}) = \text{SDXID}^2/\text{NID} \quad (6)$$

Division by the sample size is appropriate because XIN and XID are averages.

(B-40)

$$\text{Var}(XT24) = \frac{1}{(\text{NTN} + \text{NTD})^2} [\text{NTN}^2 \text{Var}(XTN) + \text{NTD}^2 \text{Var}(XTD)] , \quad (7)$$

where

$$\text{Var}(XTN) = \text{SDXTN}^2/\text{NTN} \text{ and } \text{Var}(XTD) = \text{SDXTD}^2/\text{NTD} .$$

Finally, two standard deviations of $f_{I,1}$ is calculated as:

$$\text{TSDFI1} = 2 \sqrt{\text{Var}(\text{FI1})} . \quad (8)$$

TSDFI1 values are given in Table B-19. To a first approximation, $\text{FI1} \pm \text{TSDFI1}$ provides an estimate of a 95% confidence interval for the true FI1 value.

(2) FI2 (= $f_{I,2}$)

$$\text{FI2} = \frac{0.375(\text{YIN}/\text{ZIN}) + 0.625(\text{YID}/\text{ZID})}{\text{YT24}/\text{ZT24}} \quad (9)$$

where YT24 and ZT24 are defined in a manner analogous to XT24 in Eq. (2).

Application of Eq. (3) is appropriate again. In this case $Y = 0.375(\text{YIN}/\text{ZIN}) + 0.625(\text{YID}/\text{ZID})$, $Z = \text{YT24}/\text{ZT24}$, and again $\text{Cov}(Y, Z) = 0$. Also, since night and day intake or transect samples are assumed to be statistically independent, $\text{Cov}(\text{YIN}/\text{ZIN}, \text{YID}/\text{ZID}) = 0$.

Thus,

$$\begin{aligned} \text{Var}(\text{FI2}) = (\text{FI2})^2 \left\{ \frac{0.375^2 \text{Var}(\text{YIN}/\text{ZIN}) + 0.625^2 \text{Var}(\text{YID}/\text{ZID})}{[0.375(\text{YIN}/\text{ZIN}) + 0.625(\text{YID}/\text{ZID})]^2} \right. \\ \left. + \frac{\text{Var}(\text{YT24}/\text{ZT24})}{(\text{YT24}/\text{ZT24})^2} \right\} \quad (10) \end{aligned}$$

Again applying Eq. (3),

$$\text{Var}(\text{YIN}/\text{ZIN}) = \left(\frac{\text{YIN}}{\text{ZIN}} \right)^2 \left[\frac{\text{Var}(\text{YIN})}{\text{YIN}^2} + \frac{\text{Var}(\text{ZIN})}{\text{ZIN}^2} - \frac{2 \text{Cov}(\text{YIN}, \text{ZIN})}{\text{YIN} \cdot \text{ZIN}} \right] \quad (11)$$

(B-41)

where $\text{Var}(\text{YIN}) = \text{SDYIN}^2/\text{NIN}$ and $\text{Var}(\text{ZIN}) = \text{SDZIN}^2/\text{NIN}$, in a manner analogous to Eqs. (5) and (6), and

$$\text{Cov}(\text{YIN}, \text{ZIN}) = r_{\text{YIN}, \text{ZIN}} \sqrt{\text{Var}(\text{YIN}) \cdot \text{Var}(\text{ZIN})} . \quad (12)$$

The staff's analysis in Section B.3.a of the correlation between number of yolk-sac larvae or post yolk-sac larvae in a sample and the volume of the sample indicates the absence of a statistically significant correlation in 9 out of the 10 cases. Thus, the staff has assumed that the r value in Eq. (12) is equal to zero, which means that the covariance term on the right side of Eq. (11) drops out.

A similar development of the type in Eqs. (11) and (12) applies to $\text{Var}(\text{YID}/\text{ZID})$ and $\text{Var}(\text{YT24}/\text{ZT24})$ in Eq. (10). In the latter case $\text{Var}(\text{YT24})$ and $\text{Var}(\text{ZT24})$ are calculated using equations analogous to Eq. (7).

Once $\text{Var}(\text{FI2})$ is calculated, two standard deviations of $f_{I,2}$ is calculated as

$$\text{TSDFI2} = 2 \sqrt{\text{Var}(\text{FI2})} . \quad (13)$$

TSDFI2 values are given in Table B-19. Again, to a first approximation, $\text{FI2} \pm \text{TSDFI2}$ provides an estimate of a 95% confidence interval for the true FI2 value.

An examination of the $f_{I,1}$, $f_{I,2}$, and "two standard-deviation" values in Table B-19 indicates that 9 of the 26 approximate confidence intervals include (or exceed) 1.0. In the other 17 cases, the data themselves, apart from problems with the sampling design and sampling techniques, do suggest f_I values of less than 1.0.

d. Comparison of Intake and Discharge Concentrations

The intake and discharge concentrations for yolk-sac larvae, post yolk-sac larvae, and nonscreenable juveniles at Bowline are summarized in Table B-20. The staff's analysis indicates that:

- (1) the concentration of yolk-sac larvae tends to be lower in the discharge samples than in the intake samples;
- (2) the concentration of post yolk-sac larvae tends to be lower in the discharge samples than in the intake samples;

(B-42)

- (3) the concentration of nonscreenable juveniles tends to be higher in the discharge samples than in the intake samples;
- (4) in all cases the variability is too large to say whether these indications of differences are real.

Table B-20. Intake and discharge 24-hr average concentrations^a for yolk-sac larvae, post yolk-sac larvae, and juveniles at Bowline^b

Life stage	Date	Intake			Discharge		
		Sample size	24-hr Average (number/1000 m ³)	Standard deviation (number/1000 m ³)	Sample size	24-hr Average (number/1000 m ³)	Standard deviation (number/1000 m ³)
Yolk-sac larvae	6/13-14	20	100.0	307.8	17	26.2	66.6
	6/27-28	28	0	0	9	0.6	1.7
Post yolk-sac larvae	6/13-14	20	153.2	460.7	17	40.3	139.1
	6/27-28	28	31.7	65.9	9	25.5	58.1
Juveniles	6/27-28	28	6.7	26.0	9	12.1	30.8

^aTwenty-four hour average concentrations calculated as the average of the individual concentrations.

^bDischarge data at the other plants were not adequate for this analysis.

The intake velocity is 0.2 to 0.3 fps at Bowline, while the velocity at the point of sampling in the discharge is 8 to 10 fps.

The staff's a priori reasoning was that, because of this large difference in water velocity at the two sampling points at Bowline (similar differences exist at the other plants), there would be apparent concentration differences even if in fact there were not. The staff reasons [Sections V.D.2.b(2)(e) and V.D.2.e(3)] that the concentration of yolk-sac larvae might be lower in the discharge samples at higher velocities due to net damage and bursting of the relatively fragile yolk-sac stage. On the other hand, the staff reasons that the concentration of juveniles (or in general, life stages with high avoidance ability) might be lower in the intake samples due to net avoidance; avoidance is less likely to occur in the discharge at the higher velocities, particularly if passage through the plant kills the organisms.

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After analyzing the Bowline data, the staff's conclusion is that the data are consistent with the staff's a priori reasoning but too variable to verify it. There is not sufficient information to offer a sound interpretation of the results for post yolk-sac larvae.

e. Comparison of Bowline Pond and Bowline Transect Data

An analysis similar to the one given in Section B.3.b and B.3.c, comparing the intake and transect data at Bowline, Lovett, Danskammer, and Roseton, is given here for the Bowline Pond and Bowline transect data. Results are given in Table B-21, which is similar in format to Table B-19; each of the acronyms has the same definition as given in Table B-18 except that Bowline Pond must be substituted for intake wherever the word "intake" appears.

This analysis indicates f_I may be less than 1.0 for yolk-sac larvae and post yolk-sac larvae, but it may be greater than 1.0 for juveniles. The staff's understanding is that the same sampling techniques (e.g., nets, towing speeds, and towing times) were used in Bowline Pond and in the Bowline transect. For this reason the staff places greater confidence in the f_I values calculated from these data than in the f_I values calculated from intake and transect data collected using significantly different sampling techniques [see Sections V.D.2.b(2)(e) and V.D.2.e]. The staff's best judgment is that an f_I value of 0.5 is reasonable for yolk-sac larvae and post yolk-sac larvae at Bowline. On the other hand, the data available to the staff suggest that the juveniles may be using Bowline Pond as a shoaling area and that an f_I value of 2.0 is reasonable.

f. Tests for Normality and Homogeneity of Variance

Parametric tests of statistical significance, whether they involve hypothesis testing or confidence intervals, are based on the assumptions that for each subset of the total data set the random variable is normally distributed and that among the various subsets the true variance is the same. For this reason the staff has examined the concentration values and the logarithms of the concentrations values for normality and homogeneity of variance. (The logarithmic transformation is the most commonly used transformation in analyzing plankton data.)¹⁻³

The normality assumption was examined by (1) plotting histograms of concentration and $\log_{10}$ (concentration) for yolk-sac larvae and post yolk-sac larvae for each plant (totaled over dates) and for each date at each plant, (2) plotting $\log_{10}$ (concentration) versus cumulative percent frequency for selected life stages, plants, and

Table B-21. Sample size, mean and standard deviation for night and day, Bowline Pond and transect values for number of organisms, volume of sample, and concentration. Also tabulated are intake f factor values (f_i), calculated using four techniques and approximate 95% confidence intervals for $f_{1,1}$ and $f_{1,2}$. Values are given for yolk-sac larvae, post yolk-sac larvae, and juveniles. Acronyms are defined in Table B-18.

Material under the second two sets of headings is a continuation of that under the first; note the values in the "OBS" column.

OBS	PLANT	DATE	STAGE	NTN	YTN	SDYTN	ZTN	SDZTN	XTN	SDXTN	NTD	YTE	SDYTE	ZTD	SDZTD	XTD
1	1	1	1	9	6.110	9.14	.196	.0410	36.3	52.5	18	9.440	22.61	.165	.0165	58.50
2	1	1	2	9	29.670	27.26	.196	.0410	141.8	115.8	18	14.170	35.78	.165	.0165	87.20
3	1	2	1	15	0.733	2.34	.100	.0625	5.7	15.3	26	0.846	1.85	.151	.0500	5.79
4	1	2	2	15	24.000	25.04	.100	.0625	331.2	445.1	26	3.170	7.24	.151	.0500	16.10
5	1	2	3	15	6.130	8.56	.100	.0625	73.6	104.7	26	0.800	0.00	.151	.0500	0.00
OBS	SDXID	NTN	YTN	SDYTN	ZTN	SDZTN	XTN	SDXTN	NTD	YTE	SDYTE	ZTD	SDZTD	XTD	SDXTD	
1	142.9	20	36.85	28.40	.162	.0271	223.7	156.1	56	20.14	33.70	.166	.0188	129.80	214.9	
2	221.0	20	52.00	39.64	.162	.0271	313.5	215.7	56	22.71	50.50	.166	.0188	156.70	369.1	
3	14.7	15	7.07	12.94	.180	.0280	37.1	59.5	41	23.66	46.84	.178	.0295	152.80	317.3	
4	32.5	15	66.87	66.19	.180	.0280	396.5	417.1	41	79.54	133.94	.178	.0295	503.60	904.1	
5	0.0	15	3.67	6.26	.180	.0280	21.7	39.7	41	1.32	5.40	.178	.0295	8.19	34.4	
OBS	PLANT	DATE	STAGE	FI1	TSOPI1	FI2	TSOPI2	FI3	FI4							
1	1	1	1	0.32474	0.30144	0.31896	0.65619	0.33729	0.30708							
2	1	1	2	0.54391	0.41752	0.59889	1.25536	0.55389	0.55789							
3	1	2	1	0.04726	0.04764	0.05807	0.14298	0.05348	0.05131							
4	1	2	2	0.28271	0.22260	0.24275	0.54961	0.31480	0.21801							
5	1	2	3	2.33725	2.55999	2.10524	5.31045	2.52766	1.94665							

(B-45)

sampling dates, and (3) using the Kolmogorov-Smirnov test for goodness of fit to normality^{4,5} for yolk-sac larvae and post yolk-sac larvae for Lovett.

The histograms clearly indicated that the untransformed concentration values were strongly skewed toward zero. The logarithmic transformation reduced the skewness, but there was still an excess of low values. The excess of low values is illustrated in Fig. B-11a, which is plot of the logarithm of the concentration of yolk-sac larvae versus cumulative percent frequency for the transect samples at Bowline on June 13-14, 1973. If the observations were distributed normally, they would fall on a straight line. The results of the Kolmogorov-Smirnov test for goodness of fit are summarized for the Lovett data in Table B-21a. In 17 out of the 18 tests the assumption of normality is rejected.

The staff concludes that neither the concentration values nor the logarithms of the concentration values are normally distributed, although the latter do not violate the assumption of normality as severely.

The homogeneity of variance assumption was examined by (1) plotting the means versus the variances for concentration and $\log_{10}$ (concentration) values and (2) using an F-test (2-sided) for homogeneous variance for the $\log_{10}$ (concentration) values. The plots with untransformed data indicated larger variances with larger means, but this dependence of the variance on the mean was largely eliminated by the logarithmic transformation. In 13 out of the 17 F-tests performed on the transformed data the null hypothesis of homogeneous variances was not rejected at the 5% level of significance. The staff concludes that the log-transformed data do not in general violate the assumption of homogeneity of variance. The results of this subsection are made use of in the next subsection.

g. Tests for Significant Differences Between Intake and Transect Means and Medians

In both the staff's and the applicant's striped bass y-o-y models, the appropriate manner in which to allow for the possibility that the average intake concentration of striped bass ichthyoplankton may differ from the average transect or segment concentration is by means of a multiplicative ratio such as f_I (in the staff's model) or $f_1 \cdot f_2$ (in the applicant's model). As indicated in Sect. B.3.c, it is possible to place an approximate 95% confidence interval around a calculated f_I value and on the basis of such an analysis to tentatively conclude whether or not the calculated f_I value differs significantly from 1.0. If f_I is statistically significantly less than 1.0, this suggests that the intake concentration is statistically significantly less than the transect concentration.

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Fig. B-11a. Plot of the logarithm of the concentration of yolk-sac larvae versus cumulative percent frequency for the transect samples at Bowline on June 13-14, 1973. The excess of low values, and thus the deviation from a normal distribution, is indicated by the deviation of the points from a straight line.

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Table B-21a. Results of the Kolmogorov-Smirnov test for goodness of fit of the 1973 Lovett data to a normal distribution

Life stage	Date ^a	Site ^b	Sample size	Probability of obtaining the observed D	Reject null hypothesis
Yolk-sac larvae	All	All	160	<0.01	Yes
	6/5-6	All	90	<0.01	Yes
	6/19-20	All	70	<0.01	Yes
	All	Intake	26	<0.01	Yes
	All	Transect	134	<0.01	Yes
	6/5-6	Intake	15	<0.01	Yes
	6/5-6	Transect	75	>0.20	No
	6/19-20	Intake	11	<0.05	Yes
	6/19-20	Transect	59	0.01	Yes
Post yolk-sac larvae	All	All	149	<0.01	Yes
	6/19-20	All	70	<0.01	Yes
	7/3-4	All	79	<0.01	Yes
	All	Intake	25	<0.01	Yes
	All	Transect	124	<0.01	Yes
	6/19-20	Intake	11	<0.01	Yes
	6/19-20	Transect	59	<0.01	Yes
	7/3-4	Intake	14	<0.01	Yes
	7/3-4	Transect	65	<0.01	Yes

^a"All" means June 5-6 and June 19-20 data combined for yolk-sac larvae and June 19-20 and July 3-4 data combined for post yolk-sac larvae.

^b"All" means intake and transect data combined.

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However, there is a much more direct approach available to test the hypothesis that the intake concentration is significantly less than the transect concentration.

The staff has tested the null hypothesis that the mean intake concentration is greater than or equal to the mean transect concentration using a t-test on the $\log_{10}$ (concentration) values. Since a t-test is a parametric technique, it is assumed that the observations within each subset of the total data set are normally distributed and that among the subsets the true variance is the same (see Sect. B.3.f). The staff also has tested the null hypothesis that the median intake concentration is greater than or equal to the median transect concentration using the median test^{4,5} on the untransformed concentration values.

The results of these two methods of analysis are summarized in Table B-21b. There are significant differences (at the 5% level) between intake and transect mean $\log_{10}$ (concentration) values in 11 of the 17 t-tests. There are significant differences (at the 5% level) between intake and transect median concentration values in 10 of the 17 median tests. Because the log transformed data are not normally distributed (Sect. B.3.f), the staff has greater confidence in the nonparametric median test.

On the basis of the analysis in this subsection, apart from problems with the sampling design and sampling techniques, the staff concludes that for striped bass, yolk-sac larvae and post yolk-sac larvae in particular, the mean and the median concentrations entering the intakes at Bowline, Lovett, Danskammer, and Roseton are less than the mean and median concentrations in the transects the majority of the time. This conclusion is in agreement with the conclusion of Sect. B.3.c.

h. The Appeal Board's Conclusion with Respect to the f_1 Factor

The Atomic Safety and Licensing Appeal Board concluded in its decision on Indian Point Unit No. 2²⁰ (p. 132) that "both the applicant and staff data support an f_1 factor of considerably less than 1.0." The staff is in agreement with this conclusion, but the staff feels that certain aspects of this issue need further clarification. Figure B-11b should be referred to as an aid in understanding the following line of reasoning.

1) The applicant defines f_1 as the ratio of the daily average river concentration of stage i in the upper east (or west) quadrant to the daily average river concentration of stage i in the entire transect.⁵⁷

Table B-21b. Summary of results from t-tests and median tests by plant, date, and life stage for the null hypothesis that the mean intake $\log_{10}$ (conc) or median intake conc $\geq$ mean transect $\log_{10}$ (conc) or median transect conc

Plant	Date	Life stage ^a	t-Test			Combined sample size	Combined median (M) ^c	Median test				Reject H ₀ ^d (α = 0.05)
			Mean concentration ^b		Reject H ₀ ^d (α = 0.05)			Intake		Transect		
			Intake	Transect				Number > M	Number ≤ M	Number > M	Number ≤ M	
Bowline	6/13-14+	YSL	30.3	122.3	Y	133	5.92	1	32	64	36	Y
	6/27-28]	PYSL	67.6	310.7	Y	133	23.7	6	27	60	40	Y
	6/13-14	YSL	138.9	154.7	Y	67	8.13	1	11	32	23	Y
		PYSL	211.0	198.0	N	67	6.02	3	9	30	25	N
	6/27-28	YSL	0	121.8	Y	66	2.41	0	21	33	12	Y
		PYSL	33.8	474.9	Y	66	62.3	5	16	28	17	Y
		JUV	8.78	11.8	N	66	0	2	19	14	31	N
Lovett	6/5-6+	YSL	0.76	1.56	Y	160	35.1	7	19	73	61	Y
	6/19-20]											
	6/19-20+	PYSL	0.56	1.36	Y	149	13.3	8	17	66	58	N
	7/3-4]											
	6/5-6	YSL	6.25	105.3	Y	90	28.5	2	13	43	32	Y
	6/19-20	YSL	54.8	146.8	N	70	44.8	4	7	31	28	N
		PYSL	36.3	418.6	Y	70	77.9	2	9	33	26	Y
	7/3-4	PYSL	4.63	29.2	Y	79	6.80	2	12	38	27	Y
JUV		0	3.73	Y	79	0	0	14	21	44	Y	
Danskammer	6/7-8	YSL	193.2	598.9	N	36	177.9	7	9	11	9	N
	6/19-20	PYSL	31.9	35.6	N	51	14.7	9	7	16	19	N
Roseton	7/2-3	PYSL	96.0	7.20	N	60	0	5	9	12	34	N

^aYSL = yolk-sac larvae; PYSL = post yolk-sac larvae; JUV = juveniles.

^bConcentrations have units of number of organisms per 1000 cubic meters. The analysis of variance F test was for the intake and transect mean $\log_{10}$ (concentration) values and not the mean concentration values given in these two columns.

^cM has units of number of organisms per 1000 cubic meters.

^dY = yes and N = No. H₀: mean intake $\log_{10}$ (conc) [or median intake conc] $\geq$ mean transect $\log_{10}$ (conc) [or median transect conc].

(B-50)

Fig. B-11b. Hypothetical cross section of the Hudson River illustrating the applicant's four quadrants, the location of the three typical sampling stations and sampling depths, and a band of relatively high concentration of striped bass ichthyoplankters along the river bottom.

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2) The applicant defines⁵⁷ the upper east (west) quadrant as "extending from mid-channel to the east (west) shore and from surface to mid-depth."

3) The concentrations used in the calculation of f_1 values are based on surface and bottom samples and a variable number of intermediate-depth samples; generally these samples are collected at three stations (east, mid-channel, and west).¹⁸ A mid-depth concentration is calculated as the average of the concentrations in the intermediate-depth sample. Each of the stations typically has a depth of two or more times the depth of the intake structure. For example at Lovett, the river depth of the west sampling station was 60 feet, while the intake structure goes from the surface to the bottom of the river, which at that point is approximately 20 feet.

4) The measured vertical distributions of entrainable life stages of striped bass all indicate a tendency for higher concentrations toward the bottom than toward the surface, regardless of depth.^{59,60} In other words, striped bass ichthyoplankters tend to be concentrated toward the bottom of the river whether the bottom is near an intake in 20 or 30 feet of water or in the middle of the channel in 100 feet of water.

5) There do not appear to be systematic lateral (i.e., across the river from the east to the west shore) differences in the average concentration in the water column of striped bass eggs, yolk-sac larvae, and post yolk-sac larvae.^{61,62}

6) Given items (1) through (5) above, the staff would expect a priori, without analyzing a given set of transect data, that calculated values of f_1 would be less than 1.0.

7) The applicant defines f_2 ⁵⁷ as the ratio of the daily average concentration of stage i in the water actually entering the plant to the daily average river concentration of stage i in the upper east (or west) quadrant.

8) The concentrations used to estimate the numerator of f_2 are based on samples collected at the surface, mid-depth, and bottom of the intake structure, which in all cases rests on the bottom of the river.

(B-52) 9) Given items (2) to (8), the staff would expect a priori that calculated values of f_2 would be ≥ 1.0 . [The values of f_2 at a particular power plant would depend on the bottom profile in the immediate vicinity of the intake and the distribution of the streamlines into the intake.] Stated another way, no bottom samples (again, which tend to have higher concentrations) are used to estimate the average daily river concentration of stage i in the upper east (or west) quadrant, whereas bottom samples are used to estimate the average daily concentration of stage i in the water actually entering the plant.

10) What is relevant in determining the actual impact and the impact forecast by QLM's and the staff's models is the average daily value of the product of f_1 and f_2 , i.e., f_I .

In summary, the points the staff has attempted to clarify in this subsection are that the staff would expect calculated values of f_1 to be less than 1.0 and calculated values of f_2 to be ≥ 1.0 , and that what is relevant in determining the actual impact and the impact forecast by the models is the product of f_1 and f_2 .

References for Section 5.4.1.2
(from material excerpted in IP3 FES)

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3. Cassie, R. M., "Sample Design," *Monogr. Oceanogr. Methodology* 2: 105-121, 1968.
4. Siegel, S., *Nonparametric Statistics*, McGraw-Hill, New York, 1956.
5. Sokal, R. R., and F. J. Rohlf, *Biometry*, Freeman, San Francisco, 1969.
18. Letter dated August 15, 1974, from E. R. Fidell, LeBoeuf, Lamb, Leiby, and McRae to M. J. Oestmann, USAEC, including information about Quirk, Lawler, and Matusky Engineers" 1973 factor studies at the Lovett, Bowline, Danskammer, and Roseton power plants.
19. Cochran, W. G., "Ratio Estimates," Chapter 6 in *Sampling Techniques*, John Wiley and Sons, Inc., N. Y., pp. 154-188, 1963.
20. Atomic Safety and Licensing Appeal Board, "In the Matter of Consolidated Edison Company of New York, Inc. (ALAB-188), Docket No. 50-247," in *Regulatory Adjudicatory Issues*, vol. 4, 323-409, 1974.
57. Testimony of J. P. Lawler, "Effect of Entrainment and Impingement at Indian Point on the Population of the Hudson River Striped Bass," Docket No. 50-247, October 30, 1972.
59. New York University Medical Center, Institute of Environmental Medicine, Laboratory for Environmental Studies, "Hudson River Ecosystem Studies, Effects of Entrainment by the Indian Point Power Plant on Hudson River Estuary Biota, Progress Report for 1971 and 1972," prepared for Consolidated Edison Company of New York, Inc., September 1973 (issued March 1974).
60. New York University Medical Center, Institute of Environmental Medicine, Laboratory for Environmental Studies, "Hudson River Ecosystem Studies, Effects of Entrainment by the Indian Point Power Plant on Biota in the Hudson River Estuary, Progress Report for 1973," prepared for Consolidated Edison Company of New York, Inc., September 1974.

61. U.S. Atomic Energy Commission, In the Matter of Consolidated Edison Company of New York, Inc. (Indian Point Station, Unit No. 2), Docket No. 50-247, ASLB Hearing Transcripts, pp. 7060-7092.
62. Testimony of R. J. Griemsmann, "Distribution of Early Life Stages of Striped Bass Near Indian Point and Mortality of Early Life Stages of Striped Bass on Passage through Indian Point," Docket No. 50-247, February 19, 1973.

5.4.2 New information

Since preparation of the Indian Point Unit No. 3 Final Environmental Statement, new information relevant to f_1 has been received for the Indian Point, Bowline, and Lovett power plants. This information is summarized below. Comparable new information for the Roseton and Danskammer plants became available only after the cutoff date of March 1976 for material to be considered in this report; this information has not been analyzed and will not be discussed.

As was noted in the material excerpted from the IP3 FES in Section 5.4.1, the absolute collection efficiency (and in some cases, the relative collection efficiency) of the gear used in entrainment sampling is unknown, although it likely becomes progressively lower for later life stages. Because of the unknown efficiency, no attempt is made to estimate the numbers of early life stages which might be entrained at the various plants.

5.4.2.1 1973 studies at Indian Point. New York University conducted comparative abundance studies in the Hudson River in the vicinity of Indian Point, at the intakes of Units 1 and 2, and in the Indian Point discharge canal in 1973.¹ Figure 5.3.1 shows schematically the general location of the intake and discharge sampling stations, although in 1973 the Unit 2 sampling was done in the outer forebays. Figure 5.4.1 shows details of the sampling rig used, and Fig. 5.4.2 shows the sampling location in the Unit No. 1 intake structure. Velocities varied between sampling locations and were dependent on the plant operating status. Table 5.4.1 indicates the range of possible sampling velocities at different in-plant locations.

River sampling was conducted along four transects, as shown in Fig. 5.4.3. Table 5.4.2 provides more detailed information about the depth at each station and the location of each station relative to Indian Point.

Sampling gear and conditions differed between the plant sampling and the river sampling in several respects. Sampling nets used in the river studies were longer than those used in the in-plant studies (3.8 m in the river vs 1.2 m at the Unit 2 intake and 1.9 m at the other in-plant stations). Sampling velocities (water velocity relative to the net) were higher (1.0 to 1.5 m/sec) in the river than at the intakes (less than 0.15 m/sec). Actual discharge sampling velocities were not given for most dates, and the distribution of catch by dates is not provided, but the available information (ref. 1, p. 244) suggests that discharge sampling velocities were generally lower than river sampling velocities. Sampling times were considerably shorter in the river (10 min) than at the in-plant stations (50 min). All nets had a mouth diameter of 0.5 m and were fished at the surface, at middepth, and near the bottom until July 24, when use of a Hensen net with a 1-m opening, fished only at the surface and bottom, was initiated for river samples. A limited study to compare the effectiveness of the river nets with that of the nets used in the in-plant studies was apparently carried out (ref. 1,

Fig. 5.4.1. Rig used for intake and discharge canal sampling.
 Source: New York University, Institute of Environmental Medicine,
*Hudson River Ecosystem Studies, Effects of Entrainment by the Indian
 Point Power Plant on Biota in the Hudson River Estuary, Progress Report
 for 1973*, prepared for Consolidated Edison Company of New York, Inc.,
 September 1974, Fig. 1-10.

Fig. 5.4.2 Cross section through Unit 1 forebay showing position of sampling nets. The mouths of the nets are approximately 6 in. behind the bar racks. The configuration of the Unit 2 forebays is similar, but the distance between the bar racks and the traveling screen is greater, permitting the nets to be mounted about 3 ft back from the bar racks. Also, the floor under the pump intake pipe in Unit 2 is sloped rather than stepped. Source: New York University, Institute of Environmental Medicine, *Hudson River Ecosystem Studies, Effects of Entrainment by the Indian Point Power Plant on Biota in the Hudson River Estuary, Progress Report for 1973*, prepared for Consolidated Edison Company of New York, Inc., September 1974, Fig. 1-11.

Table 5.4.1. Estimated cross-sectional flow velocities at existing and proposed sampling points in the Indian Point plant cooling water system when operating at 100% of design flow and at mean low water in the Hudson River

(The numbers given decrease by 10% at high slack tide and by 5% at low slack tide. The numbers decrease by 40% when the system is operating at 60% of design flow. At units 1 and 2, the sampling rigs are positioned between the trash bars and the traveling screens, as shown in Fig. 5.4.2. In the Unit 3 intakes, the traveling screens will be located immediately inside the intake openings so that the sampling rigs will be positioned between the traveling screens and the pumps)

Sampling location	Velocity (fps) with indicated generating units operational						
	1	2	3	1+2	1+3	2+3	1+2+3
Intake							
Unit 1	0.7	0	0	0.7	0.7	0.7	0.7
Unit 2	0	0.9	0	0.9	0.9	0.9	0.9
Unit 3	0	0	0.9	0.9	0.9	0.9	0.9
Discharge canal							
Station D-1	1.1	3.1	0	4.4	1.1	3.3	4.4
Station D-3	0	0	6.6	0	6.6	6.6	6.6
Station D-2	0.8	2.5	2.5	3.4	3.4	5.0	5.8
Station DP	10.0	10.0	10.0	10.0	10.0	10.0	10.0

Source: New York University, Institute of Environmental Medicine, *Hudson River Ecosystem Studies, Effects of Entrainment by the Indian Point Power Plant on Biota in the Hudson River Estuary*, Progress Report for 1973, prepared for Consolidated Edison Company of New York, Inc., September 1974, Table 1-2.

Fig. 5.4.3. New York University Hudson River sampling stations, 1973.
 Source: New York University, Institute of Environmental Medicine, *Hudson River Ecosystem Studies, Effects of Entrainment by the Indian Point Power Plant on Biota in the Hudson River Estuary, Progress Report for 1973*, September 1974, Fig. 1-8.

Table 5.4.2. Location of 1973 Hudson River sampling stations relative to depth contour and distance from Indian Point Unit 2 intake

Tow path	Approximate depth contour (ft)	Approximate distance from plant intake (ft)
R-1	50	125
R-2	60 - 75	1000
R-3	50	1760
R-4	25 - 30	2875

Source: New York University, Institute of Environmental Medicine, *Hudson River Ecosystem Studies, Effects of Entrainment by the Indian Point Power Plant on Biota in the Hudson River Estuary, Progress Report for 1973*, prepared for Consolidated Edison Company of New York, Inc., September 1974, Table 1-6.

p. 28), but the results have not been reported. In general, the differences between the in-plant and the river studies would lead the staff to expect a priori that the results of the sampling programs would lead to underestimates of f_I , particularly for the later life stages.

Only summary results and comparisons from the abundance sampling studies have been presented.² One set of summary comparisons (data set 1) involved the use of data for all dates on which striped bass were taken (Tables 5.4.3 and 5.4.4). A second set (data set 2) involved the use of data only from "time-coincident" river and intake samples (occurring within 2 hr of each other) (Tables 5.4.5 and 5.4.6). A breakdown of data by surface, middepth, and bottom or by sampling station is available only for data set 1. However, depth information for specific stations is not provided, and no breakdown by either specific station or by depth over all river or intake stations is provided for data set 2. Therefore, it is not possible to estimate f_I factors using a double-weighting method for middepth samples. Data from discharge samples are not provided for data set 2.

Table 5.4.7 presents ORNL comparisons of in-plant striped bass densities with river densities and calculations of f_I estimates, denoted f_{I1} . Where possible (for comparisons involving I-1, the Unit 1 intake, and I-2, the Unit 2 intake), data set 2 has been utilized. These estimates are subject to the gear biases already mentioned. Without correction for such biases, they suggest true f_I values somewhat larger than 1.0 for eggs and juveniles and values in the range of 0.5 to 1.0 for larvae.

5.4.2.2 1974 studies at Indian Point. New York University's 1974 ichthyoplankton abundance studies at Indian Point^{3,4} appear to have been similar to the 1973 studies (Sect. 5.4.2.1). However, there were certain changes in the in-plant sampling program, notably the taking of samples

Table 5.4.3. Mean abundance and 95% confidence intervals,
by station, for daytime collections in 1973: data set 1

(Abundances given as mean number per 1000 m³ of four life history stages of striped bass. Samples were collected over time periods shown. n given beneath each mean represents number of samples examined. Data set 1 used data for all dates on which striped bass were taken)

	Station	Station	Station	Station	Station	Station	Station	Station
	R-1	R-2	R-3	R-4	I-1	I-2	D-1	D-2
Eggs, 5/29-6/26	12 ± 12 n = 90	17 ± 12 n = 90	10 ± 12 n = 89	14 ± 12 n = 87	77 ± 13 n = 185	97 ± 20 n = 87	14 ± 2 n = 189	13 ± 2 n = 187
Yolk-sac larvae, 5/29-6/26	14 ± 12 n = 90	21 ± 12 n = 90	20 ± 12 n = 89	28 ± 13 n = 87	18 ± 3 n = 185	13 ± 4 n = 87	8 ± 1 n = 189	7 ± 1 n = 187
Larvae, 5/29-7/24	79 ± 47 n = 141	164 ± 47 n = 142	129 ± 47 n = 141	194 ± 47 n = 137	41 ± 4 n = 337	38 ± 6 n = 126	105 ± 15 n = 326	65 ± 14 n = 336
Juveniles, 6/12-8/21	1 ± 1 n = 72	2 ± 1 n = 73	2 ± 1 n = 73	1 ± 1 n = 71	1 ± 1 n = 260	1 ± 1 n = 80	15 ± 6 n = 268	7 ± 6 n = 277

Source: New York University, Institute of Environmental Medicine, *Hudson River Ecosystem Studies. Effects of Entrainment by the Indian Point Fawer Plant on Biota in the Hudson River Estuary. Addenda to the 1973 Report*, prepared for Consolidated Edison Company of New York, Inc., August 1976, Table 10.

Table 5.4.4. Mean abundance and 95% confidence intervals,
by station, for daytime collections in 1973: data set 1

(Abundances given as mean number per 1000 m³ of four life history stages of striped bass. Samples were collected over time periods shown. n given beneath each mean represents number of samples examined. Data set 1 used data for all dates on which striped bass were taken)

	Station	Station	Station	Station	Station	Station	Station	Station
	R-1	R-2	R-3	R-4	I-1	I-2	D-1	D-2
Eggs, 5/29-6/26	8 ± 9 n = 60	1 ± 9 n = 60	10 ± 9 n = 60	10 ± 9 n = 60	40 ± 10 n = 148	40 ± 11 n = 125	6 ± 2 n = 137	5 ± 2 n = 136
Yolk-sac larvae, 5/29-6/26	4 ± 4 n = 60	8 ± 4 n = 60	5 ± 4 n = 60	7 ± 4 n = 60	18 ± 6 n = 148	12 ± 6 n = 125	8 ± 2 n = 137	6 ± 2 n = 136
Larvae, 5/29-7/24	139 ± 70 n = 96	198 ± 70 n = 95	193 ± 70 n = 96	197 ± 70 n = 96	141 ± 34 n = 266	100 ± 38 n = 219	188 ± 28 n = 226	73 ± 27 n = 250
Juveniles, 6/12-8/21	3 ± 1 n = 51	0 ± 1 n = 50	2 ± 1 n = 51	0 ± 1 n = 51	39 ± 8 n = 213	21 ± 9 n = 171	56 ± 9 n = 177	21 ± 8 n = 200

Source: New York University, Institute of Environmental Medicine, *Hudson River Ecosystem Studies. Effects of Entrainment by the Indian Point Power Plant on Biota in the Hudson River Estuary. Addenda to the 1973 Report*, prepared for Consolidated Edison Company of New York, Inc., August 1976, Table 11.

Table 5.4.5. Mean abundance and 95% confidence intervals
for samples collected during the day and night from
the river stations and intake station I-1 in 1973:
data set 2

(Samples matched by station, date, and time. n given beneath each mean represents the number of samples examined. Data set 2 used data only from "time-coincident" river and intake samples, occurring within 2 hr of each other)

	River		I-1	
	Day	Night	Day	Night
Eggs, 5/29-6/12	26 ± 12 n = 176	14 ± 9 n = 120	153 ± 29 n = 90	66 ± 19 n = 59
Yolk-sac larvae, 5/29-6/26	20 ± 6 n = 344	6 ± 2 n = 240	17 ± 3 n = 174	10 ± 6 n = 118
Larvae, 5/29-7/24	134 ± 23 n = 549	182 ± 35 n = 383	44 ± 3 n = 314	167 ± 43 n = 224
Juveniles, 6/12-8/21	1 ± 1 n = 289	1 ± 1 n = 203	1 ± 1 n = 242	41 ± 12 n = 201

Source: New York University, Institute of Environmental Medicine, *Hudson River Ecosystem Studies. Effects of Entrainment by the Indian Point Power Plant on Biota in the Hudson River Estuary. Addenda to 1973 Report*, prepared for Consolidated Edison Company of New York, Inc., August 1976, Table 17.

Table 5.4.6. Mean abundance and 95% confidence intervals for samples collected during the day and night from the river stations and intake station I-2 in 1973: data set 2

(Samples matched by station, date, and time. n given beneath each mean represents the number of samples examined. Data set 2 used data only from "time-coincident" river and intake samples, occurring within 2 hr of each other)

	River		I-2	
	Day	Night	Day	Night
Eggs, 5/29-6/12	32 ± 15 n = 141	16 ± 10 n = 108	120 ± 22 n = 70	39 ± 26 n = 54
Yolk-sac larvae, 5/29-6/26	31 ± 13 n = 177	5 ± 2 n = 204	13 ± 3 n = 87	1 ± 1 n = 100
Larvae, 5/29-7/24	47 ± 10 n = 236	163 ± 23 n = 323	40 ± 8 n = 120	114 ± 42 n = 188
Juveniles, 6/12-8/21	1 ± 1 n = 71	1 ± 1 n = 167	1 ± 1 n = 74	21 ± 3 n = 164

Source: New York University, Institute of Environmental Medicine, Hudson River Ecosystem Studies. *Effects of Entrainment by the Indian Point Power Plant on Biota in the Hudson River Estuary. Addenda to the 1973 Report*, prepared for Consolidated Edison Company of New York, Inc., August 1976, Table 18.

Table 5.4.7. Oak Ridge National Laboratory estimates of daytime, nighttime, and weighted combined values of $\hat{f}_I$ at Indian Point, based (for the most part) on matched samples taken by New York University in 1973

(All depths evenly weighted. Matched data for discharge vs river stations were not provided. These values are therefore based on unmatched samples. Similar nets were used in all locations until July 24, at which time larger (1-m mouth diameter) nets were used in the river sampling.)

Comparison	Mean daytime concentration (number per 1000 m ³)		$\hat{f}_{I,D}$ (C_P/C_R)	Mean nighttime concentration (number per 1000 m ³)		$\hat{f}_{I,N}$ (C_P/C_R)	Weighted combined estimate of f_{I^a}
	Plant	River		Plant	River		
	(C_P)	(C_R)		(C_P)	(C_R)		
<u>Eggs</u>							
I-1 vs R	153	26	5.9	66	14	4.7	5.4
I-2 vs R	120	32	3.7	39	16	2.4	3.3
D vs R	13.5	13.3	1.0	5.5	7.25	0.76	0.92
<u>Yolk-sac larvae</u>							
I-1 vs R	17	20	0.85	10	6	1.7	1.2
I-2 vs R	13	31	0.42	1	5	0.20	0.34
D vs R	7.5	20.7	0.36	7.0	6.0	1.2	0.66
<u>Post-yolk-sac larvae</u>							
I-1 vs R	44	134	0.33	167	182	0.92	0.55
I-2 vs R	40	47	0.85	114	163	0.70	0.79
D vs R	35.0	141	0.60	131	182	0.72	0.65
<u>Juvenile 1</u>							
I-1 vs R	1	1	1.0	41	12	3.4	1.9
I-2 vs R	1	1	1.0	21	1	21	3.5
D vs R	11.0	1.5	7.3	38.5	1.25	31	16.1

^aCalculated as $\hat{f}_I = 0.625\hat{f}_{I,D} + 0.375\hat{f}_{I,N}$.

Source: Tables 5.4.3-5.4.6.

only at night, the use of shorter sampling times, the removal of flow meters from the nets, and the use of velocity reduction cones. Changes may have been made in the river sampling program as well; for example, it is unclear where the river samples were taken and whether or not the Hensen net was used in 1974. Tow speed in the river is given in terms of boat engine speed (2000 rpm) but likely corresponds to the speed of the 1973 tows.

Summary data from the 1974 program are presented in Tables 5.4.8-5.4.10. The reason for the discrepancy in the number of juveniles is not known. The discrepancy is between footnote α of Table 5.4.8, which implies that no juveniles were taken in river samples, and the data in Table 5.4.10, which imply the capture of at least two juveniles in the river. Even more puzzling is the conflict between Tables 5.4.8-5.4.9 and Table 5.3.2, which indicates that 47 juveniles were taken in intake and discharge sampling. The source report for all these tables states, "Abundance determinations were made from the same samples used to estimate ichthyoplankton viability and latent mortality effects" (ref. 3, p. 282). Pending resolution of these problems, ORNL has not attempted to calculate f_I values for juveniles from these data.

Time-coincident data have not been presented, and ORNL has therefore been forced for the time being to use the data as presented. Table 5.4.11 shows ORNL estimates of a nighttime f_I value based on an even weighting of the data at all depths. Because the middepth net can be considered to sample a larger stratum of water than either the surface or the bottom net (Fig. 5.4.1), an alternative approach is to double-weight the densities estimated by the middepth net. This approach has been used by ORNL in Table 5.4.12. A comparison of the $f_{I,N}$ values in these two tables indicates that, at least for the 1974 data, the two weighting schemes produce generally similar results. Extending the comparison to the $f_{I,N}$ values in Table 5.4.7 indicates that the 1973 estimates are generally similar to the 1974 estimates. Data presented for juveniles in 1974 are contradictory and, in any case, were not presented in a form which would permit inclusion in Tables 5.4.11 and 5.4.12.

5.4.2.3. 1974 studies at Bowline and Lovett. Lawler, Matusky, and Skelly Engineers continued ichthyoplankton abundance studies at Bowline and Lovett in 1974⁵ (see Sect. 5.4.2.1 for an analysis of their 1973 studies). Figure 5.4.4 shows the location of the river and pond sampling transects used. River samples were collected in the vicinity of each plant on an alternating biweekly basis (i.e., with sampling at Bowline one week and Lovett the next). A 1.0-m (mouth diameter) Hensen-type plankton net of unspecified length, with 571- μ m nylon mesh and equipped with a flowmeter, was towed for 5 min (less time at Bowline Pond Short and in the discharge plume) at 85 to 95 cm/sec (2.8 to 3.1 fps) against the prevailing tide. Tows were taken at various depths during day, night, dawn, and dusk.

Samples were taken at the intakes of both plants on a weekly basis. Intake flow velocities (and therefore sampling velocities) were not

Table 5.4.8: Abundance of striped bass collected in the river and at intake and discharge-canal station, 1974

(Data are mean numbers collected per 1000 m³, with 95% confidence intervals.
n = number of samples)

	Unit 1 intake	Unit 2 intake	Discharge canal	River
Eggs, 5/21 - 6/4	113 ± 38 n = 282	210 ± 71 n = 131	100 ± 23 n = 203	20 ± 14 n = 111
Yolk-sac larvae, 5/21 - 6/4	32 ± 7 n = 282	48 ± 17 n = 131	20 ± 9 n = 203	38 ± 12 n = 111
Larvae, 5/28 - 7/9	46 ± 9 n = 450	70 ± 15 n = 162	112 ± 14 n = 426	117 ± 22 n = 168
Juveniles ^a	0	0	0	0

^aOnly one juvenile was caught during the sampling period, on June 28, in a discharge-canal bottom sample.

Source: New York University, Institute of Environmental Medicine, *Hudson River Ecosystem Studies, Effects of Entrainment by the Indian Point Power Plant on Biota in the Hudson River Estuary, Progress Report for 1974*, prepared for Consolidated Edison Company of New York, Inc., February 1976, Table 7-26.

Table 5.4.9. 1974 striped bass abundance by depth with
95% confidence intervals for in-plant samples

(Data are mean numbers collected per 1000 m³.
n = number of samples)

	Surface	Middle	Bottom
<u>Unit 1 intake</u>			
Eggs, 5/21-6/4	129 ± 49 n = 94	78 ± 49 n = 94	132 ± 49 n = 94
Yolk-sac larvae, 5/21-6/4	36 ± 13 n = 94	23 ± 13 n = 94	38 ± 13 n = 94
Larvae, 5/28-7/29	56 ± 16 n = 150	50 ± 16 n = 150	32 ± 16 n = 150
Juveniles	0	0	0
<u>Unit 2 intake</u>			
Eggs, 5/21-6/4	167 ± 123 n = 44	140 ± 125 n = 43	321 ± 123 n = 44
Yolk-sac larvae, 5/21-6/4	23 ± 29 n = 44	41 ± 29 n = 43	80 ± 29 n = 44
Larvae, 5/28-7/9	75 ± 26 n = 54	58 ± 26 n = 54	75 ± 26 n = 54
Juveniles	0	0	0
<u>Discharge canal</u>			
Eggs, 5/21-6/4	97 ± 39 n = 67	105 ± 39 n = 68	98 ± 39 n = 68
Yolk-sac larvae, 5/21-6/4	35 ± 15 n = 67	19 ± 15 n = 68	18 ± 15 n = 68
Larvae, 5/28-7/9	101 ± 23 n = 142	121 ± 23 n = 142	114 ± 23 n = 142
Juveniles	0	0	0

Source: New York University, Institute of Environmental Medicine, Hudson River Ecosystem Studies, Effects of Entrainment by the Indian Point Power Plant on Biota in the Hudson River Estuary, Progress Report for 1974, prepared for Consolidated Edison Company of New York, Inc., February 1976, Table 7-28.

Table 5.4.10. Day and night striped bass abundance
in the Hudson River by depth, 1974

(Data are mean numbers collected per 1000 m³, with 95% confidence
intervals. n = number of samples)

	Surface	Middle	Bottom
<u>Day</u>			
Eggs, 5/7-6/11	21 ± 201 n = 41	92 ± 203 n = 40	341 ± 192 n = 45
Yolk-sac larvae, 5/7-6/25	1 ± 35 n = 55	52 ± 35 n = 54	91 ± 33 n = 61
Larvae, 5/7-7/19	0 ± 67 n = 69	120 ± 68 n = 68	155 ± 64 n = 77
Juveniles, 6/25-7/2	0 ± 0 n = 14	1 ± 0 n = 14	0 ± 0 n = 16
<u>Night</u>			
Eggs, 5/8-6/13	3 ± 24 n = 37	2 ± 24 n = 37	55 ± 24 n = 37
Yolk-sac larvae, 5/8-6/13	9 ± 21 n = 37	46 ± 21 n = 37	59 ± 21 n = 37
Larvae, 5/16-7/9	152 ± 38 n = 57	94 ± 38 n = 58	106 ± 40 n = 53
Juveniles, 6/13, 9/17	0 ± 0 n = 14	1 ± 0 n = 14	0 ± 0 n = 14

Source: New York University, Institute of Environmental Medicine,
*Hudson River Ecosystem Studies, Effects of Entrainment by the Indian
Point Power Plant on Biota in the Hudson River Estuary, Progress Report
for 1974*, prepared for Consolidated Edison Company of New York, Inc.,
February 1976, Table 7-4.

Table 5.4.11. ORNL estimates of nighttime values of f_I denoted $\hat{f}_{I,N}$,
 based on 1974 sampling by New York University:
 all depths evenly weighted

(Source of data is Table 5.4.8. I-1, I-2, D, and R denote samples from the Unit 1 intake, the Unit 2 intake, the discharge canal, and the Hudson River respectively. Insufficient information was presented for juveniles to enable a calculation to be made)

Comparison	Mean concentration (number per 1000 m ³)		$\hat{f}_{I,N}$ (C _P / C _R)
	Plant (C _P)	River (C _R)	
<u>Egg</u>			
I-1 vs R	113	20	5.7
I-2 vs R	210	20	10.5
D vs R	100	20	5.0
<u>Yolk-sac larvae</u>			
I-1 vs R	32	38	0.84
I-2 vs R	48	38	1.26
D vs R	20	38	0.53
<u>Post-yolk-sac larvae</u>			
I-1 vs R	46	117	0.39
I-2 vs R	70	117	0.60
D vs R	112	117	0.96

Table 5.4.12. ORNL estimates of nighttime values of f_I denoted $\hat{f}_{I,N}$, at Indian Point based on 1974 sampling by New York University: middepth samples double-weighted

(Source of data: Tables 5.4.9 and 5.4.10. I-1, I-2, and R denote samples from the Unit 1 intake, the Unit 2 intake, the discharge canal, and the Hudson River respectively. Insufficient information was presented for juveniles to enable a calculation to be made)

Comparison	Mean concentration (number per 1000 m ³)		$\hat{f}_{I,N}$ (C_P/C_R)
	Plant (C_P)	River (C_R)	
<u>Egg</u>			
I-1 vs R	104	15.5	6.7
I-2 vs R	192	15.5	12.4
D vs R	101	15.5	6.5
<u>Yolk-sac larvae</u>			
I-1 vs R	30.0	40.0	0.75
I-2 vs R	46.3	40.0	1.16
D vs R	22.7	40.0	0.57
<u>Post-yolk-sac larvae</u>			
I-1 vs R	47.0	111	0.42
I-2 vs R	66.5	111	0.60
D vs R	114	111	1.02

Fig. 5.4.4. 1974 aquatic ecology program, Bowline Point and Lovett generating stations, macrozooplankton and ichthyoplankton station locations. Source: Lawler, Matusky, and Skelly Engineers, 1974 *Aquatic Ecology Studies -- Bowline Point and Lovett Generating Stations*, prepared for Orange and Rockland Utilities, Inc., December 1975, Fig. VB-6.

given for individual or even grouped samples but were considerably lower (by a factor of at least 3) than river sampling velocities. A 0.5-m (mouth diameter) Hensen-type plankton net of 571 μm mesh, apparently equipped with a flowmeter, was used at the intakes. In 1973 and possibly in 1974, the entrainment sampling nets were 3 m long. Intake densities were estimated using intake flow velocities and a net "efficiency" correction, rather than flowmeter readings, because problems with flowmeter accuracy were encountered at the low intake sampling velocities. Some discharge sampling with nets was apparently done, but the only discharge abundance data that can be located concern length-frequency distributions. Overall, considerably more information from this sampling program is available than for the NYU programs at Indian Point.

Table 5.4.13 presents a summary of the striped bass results for Bowline. The peak abundance at the intake occurred on a sampling date (June 26-27) that was not a scheduled week for river sampling, but a few samples were taken in the river and in the pond during daylight hours. Very high abundances of larvae were found (even at the surface); length-frequency data indicate that these were primarily yolk-sac larvae or early post-yolk-sac larvae (as was the case at the intake). An effort has been made in Table 5.4.13 to estimate sample densities that might have been found at the other stations in the river had samples been collected there on that date.

Estimates of f_I are presented in Table 5.4.14 utilizing these "estimated" sample densities. While any procedure for estimating data not collected is not a satisfactory approach to use in obtaining reliable estimates of f_I , some conclusions are apparent that could also be reached without the use of the "estimated" sample densities. As mentioned in Sect. 5.4.1, comparisons between Bowline Pond stations and river stations are not subject to the kinds of differences in gear and sampling velocity that characterize comparisons between intake stations and river (or pond) stations. It appears that densities of late yolk-sac and early post-yolk-sac larvae in Bowline Pond are lower than those in the river. Lawler, Matusky, and Skelly's statement that the bottom strata of Bowline Pond cannot be sampled effectively leads to presently unresolved questions concerning whether this could be an important source of bias.

In comparing these results with those from the 1973 sampling (see Sect. 5.4.1), it is worth noting that the 1974 data reflect, for the most part, the distribution of late yolk-sac larvae, while the 1973 data reflected more the distribution of early post yolk-sac larvae (ref. 5, Table VB-53). The 1973 data, which included juveniles as well as younger stages, indicated a tendency for higher f_I values at Bowline with increasing age. Overall, the 1974 results are fairly consistent with the 1973 results, and the use of f_I values in the range of 0.5 to 1.0 to represent average values for the entrainable life stages still appears reasonable. Further data, including older larvae and juveniles, would of course be quite helpful in resolving the relationship between age and distribution.

Table 5.4.13. ORNL estimates of average abundance of striped bass at Bowline based on 1974 sampling by Lawler, Matusky, and Skelly Engineers over the period of occurrence of virtually all striped bass in samples

(Estimates averaged over depth and time within sampling dates; most early larvae. Two striped bass of unspecified age were captured in August 14-15 sampling; one was taken in the river and the other was taken at Bowline Pond Short. These two bass are not included in the calculations in this table. NS means no sample was taken. No day-night weighting was attempted)

Sampling dates	Nonplant weighting factor		Estimated abundance (number per 1000 m ³)						
			Plant (intake)	Pond		Discharge plume	River		
	1 ^a	2 ^b		Short	Long		West	Channel	East River mean
May 8-9	0	0	NS	0	0	0	0	0	0
May 15-16	0		0	NS	NS	NS	NS	NS	NS
May 22-23	7	0	NS ^c	2	0	8	67	14	36
June 5-6	14	10.5	6	37	50	299	247	370	129
June 12-13			2.5	NS	NS	NS	NS	NS	NS
June 19-20	10.5	10.5	3	19	10	68	45	23	24
June 26-27	7	7	18	85	(93) ^e	(207) ^e	(185) ^e	234	(97) ^e
July 2-3	7	7	2.5	2	2	0	3	11	3
July 10-11			0	NS	NS	NS	NS	NS	NS
July 17-18	0	0	0	0	0	0	0	0	0
Weighted mean density ^f									
May 20- July 6				29.5	32.4	141	126	159	66.2 117
June 3-July 6			6.4	34.2	37.0	151	125	167	66 119

^aThese weighting factors were used for nonintake samples in the estimation of missing values (footnote d) and for calculations of weighted mean concentrations over the period May 20-July 6 at locations other than at the intake (footnote e).

^bThese weighting factors were used for nonintake samples in calculating the weighted mean concentration over the period June 3-July 6 for comparison with the intake concentration (footnote e).

^c All pumps were off for repairs; insufficient data were collected.

^d No collections were made at this station on this date. Limited daytime collections were made at two stations, resulting in high abundance estimates. An estimated value, given in parentheses, was calculated by ORNL as follows: Let $C_{i,\ell}$ denote the concentration of organisms calculated from data taken during sampling period i at location ℓ , and let $W_{i,\ell}$ denote the "weight" of (number of days in the interval represented by) sampling on date i at location ℓ . $W_{i,\ell}$ is determined based on the midpoints between sampling dates. The weighted mean concentration (or density) over a specified period at location ℓ (WMC_ℓ) is then

$$WMC_\ell = \frac{\sum_{i=1}^I C_{i,\ell} W_{i,\ell}}{\sum_{i=1}^I W_{i,\ell}} ,$$

where I is the number of intervals in the specified period. A value of WMC_ℓ was calculated for each location (ℓ) except the intake, using all category 1 nonzero weighting factors, but excluding the June 26-27 weighting factors and data. For Bowline Pond Long, the estimated concentration (EC_{PL}) was calculated as

$$EC_{PL} = 85 WMC_{PL} / WMC_{PS} ,$$

where PS denotes Pond Short, PL denotes Pond Long, and 85 is the average concentration of striped bass at Pond Short in the June 26-27 samples. For other locations, the EC_ℓ values were calculated as

$$EC_\ell = 234 WMC_\ell / WMC_{RC} ,$$

where RC denotes the river channel, ℓ denotes the other location, and 234 is the average concentration of striped bass at the river channel station in the June 26-27 samples.

^e The intake value is obtained by weighing all dates between the indicates dates evenly (by seven days), but excluding the "nonsampled" date (see footnote ^c). Other values are obtained from the equation

$$WMC_{\ell} = \frac{\sum_{i=1}^I C_{i,\ell} W_{i,\ell}}{\sum_{i=1}^I W_{i,\ell}} ,$$

(see footnote *d*), calculated over the entire indicated period and including "estimated" values (see footnote *c*). Category 1 weighting factors were used for May 20-July 6, and category 2 weighting factors were used for June 3-July 6.

Source: Lawler, Matusky, and Skelly Engineers, 1974 *Hudson River Aquatic Ecology Studies - Bowline Point and Lovett Generating Stations*, prepared for Orange and Rockland Utilities, Inc., December 1975.

Table 5.4.14. ORNL estimates of evenly weighted combined day and night f_I values for striped bass (mostly early larvae) at Bowline based on 1974 sampling by Lawler, Matusky, and Skelly Engineers

(All depths evenly weighted; some missing sample densities estimated. Source of data is Table 5.4.13)

Comparison	Averaging period	Mean striped bass concentration (number per 1000 m ³)		$\hat{f}_I^a$
		Plant or pond	River	
"Pond long" vs river	May 20- July 6	32.4	117	0.28
"Pond short" vs river	May 20- July 6	29.5	117	0.25
Plant intake vs river	June 3- July 6	6.4	119	0.05

^aCalculated as the ratio of the plant or pond concentration to the corresponding river concentration. Discharge plume data were not used.

Similar summary data for sampling at Lovett are presented in Table 5.4.15. Once again, differences in sampling gear and methodology make the validity of comparing intake samples with river samples uncertain. However, since very young larvae comprise the bulk of the samples, the comparison is less tenuous. It would appear that the intake f factor for larvae of this age is substantially larger at Lovett than at Bowline.

5.4.3 Discussion

In Sect. 5.4.1, information available at the time of preparation of the Indian Point Unit 3 FES is considered in some detail. Two main problems with that information were apparent. First, due partially to somewhat infrequent sampling and partially to the inability of sampling gear to effectively sample older larvae and juveniles, the total amount of information available was not sufficient to enable precise estimates of f_I to be made. Second, gear and sampling techniques differed between the intake and river stations, and very little effort had been devoted to gear and sampling method comparison studies.

The new information does not resolve these problems. New York University's sampling frequency appears to have been higher than that of Lawler, Matusky, and Skelly Engineers, but many of the data needed for a detailed analysis are not available, and there are many questions concerning the study which need to be answered. Lawler, Matusky, and Skelly Engineers present much more of the needed information, but the fundamental problems mentioned above (particularly the second) remain. The following material from the Indian Point Unit 3 FES presents an overview of this problem. Again, as for Sects. 5.4.1.1 and 5.4.1.2, in excerpting this material, table numbers, figure numbers, reference numbers, and page and section references have been left as they appear in the IP3 FES.

Table 5.4.15. ORNL estimates of average abundance and $\hat{f}_I$, the estimate of the intake f factor, for striped bass at Lovett based on 1974 sampling by Lawler, Matusky, and Skelly Engineers, over the period of occurrence of virtually all striped bass in samples^a

(Estimates averaged over depth and time within sampling dates; mostly early larvae. NS means no samples were taken)

Date	River weighting factor ^a	Striped bass concentration (number per 1000 m ³)				$\hat{f}_I$	
		Plant (intake)	River				
			West	Channel	East		River mean
April 25-26	0	NS	0	0	0		
April 30		0 ^b	NS	NS	NS		
May 14-15	10.5	0	2	2	8 ^c		
May 21-22		1	NS	NS	NS		
May 28-29	14	29.5	141	123	92		
June 4-5		22	NS	NS	NS		
June 11-12	14	37	424	99	258		
June 18-19		66	NS	NS	NS		
June 25-26	14	104	103	165	158		
July 1-2		12	NS	NS	NS		
July 9-10 ^d	14	1	2	3	2		
July 16-17		0	NS	NS	NS		
July 23-25 ^e	10.5	0	0	2	0		
July 30-31		0	NS	NS	NS		
August 6-8 ^f	0	0	0	0	0		
Weighted mean density ^g							
(May 11-July 28)		38.9	122	71.5	93.8	95.8	0.41
and $\hat{f}_I$ estimate							

^aThe number of days represented by each river sampling date. Weighting factors for the intake samples are constant at seven days.

^bOnly daytime samples were taken.

^cPart of the samples were not analyzed. The tabulated value includes an adjustment for this (see pp. V-26 to V-27 of the source).

^dRiver samples were collected on July 10 only.

^eIntake samples were collected on July 23-24 only.

^fIntake samples were collected on August 6-7 and river samples on August 7-8.

Footnotes for Table 5.4.15

^gLet $C_{i,\ell}$ denote the concentration of organisms calculated from data taken during sample date i at location ℓ , and let $W_{i,\ell}$ denote the "weight" of (number of days in the interval represented by) sampling on date i at location ℓ . $W_{i,\ell}$ is determined based on the midpoints between sampling dates. The weighted mean concentration (or density) over a specified period at location ℓ (WMC_ℓ) is then

$$WMC_\ell = \frac{\sum_{i=1}^I C_{i,\ell} W_{i,\ell}}{\sum_{i=1}^I W_{i,\ell}},$$

where I is the number of intervals in the specified period. WMC_ℓ is calculated using weighting factors and data between May 11 and July 28. The estimate of f_I is obtained by dividing the intake weighted mean concentration by the river weighted mean concentration.

Source: Lawler, Matusky, and Skelly Engineers, 1974 *Hudson River Aquatic Ecology Studies - Bowline Point and Lovett Generating Stations*, prepared for Orange and Rockland Utilities, Inc., December 1975, Tables VB-37 and IX-17.

5.4.3.1 Material from Indian Point Unit 3 FES (Sect. V.D.2.e, pp. V-187 through V-191, "Ichthyoplankton Sampling").

(V-187)

(2) Considerations Relating to the Interpretation of Information about Entrainable Fish Life Stages

The considerable difficulties involved in quantitatively sampling populations of young fish are widely acknowledged.¹⁰⁰ If ichthyoplankton nets were completely efficient samplers and if young fish were uniformly distributed throughout the region, such sampling would be greatly simplified. Knowledge of the area of the mouth of the net, the velocity of the net relative to the water, and the duration of the tow would permit calculation of the concentration of organisms (number per unit volume). Multiplication of this concentration by the volume of the region would then yield the standing crop (total number of organisms in the region).

In practice, concentrations and standing crops are calculated in this manner with two modifications. Because the velocity of the water relative to the boat will often differ considerably from the velocity of the water entering the net due to vertical gradients in water velocity and resistance to water flow through the net, flowmeters are generally installed inside the nets to estimate the volume of water filtered. In addition, because the fish are known to be not uniformly (or even randomly) distributed, an estimate of average concentration and standing crop in each of the various regions is made by combining the results of a number of net tows.

(V-188)

The use of beach seine catches to estimate the population size of juvenile fish has certain obvious difficulties; this subject will be considered later in this section, following discussion of major potential sources of error in concentration and standing-crop estimates derived from net samples.

(3) Sources of Error Inherent in the Ichthyoplankton Sampling Methods

Striped bass (and other fish species) pass through several fairly distinct stages in their first year of life. When enumerated in the samples, ichthyoplankters are classified as eggs, yolk-sac larvae, post yolk-sac larvae, or juveniles, representing progressively older stages. Table V-27 indicates several sources of error that almost certainly affect estimates of population size of these various stages. Most of these will vary in importance depending on the kind of gear chosen and the method of use. The staff wishes to acknowledge discussions with personnel from New York University, Texas Instruments, and Quirk, Lawler, and Matusky Engineers, and with Dr. C. P. Goodyear and John Clark, all of whom have contributed ideas and opinions in connection with this subject. These sources of error will be individually discussed below.

Table V-27. Factors that potentially lead to the underestimation of standing crops of young-of-the-year striped bass

Source of error ^a	Life stage ^b			
	Eggs	Yolk-sac larvae	Post yolk-sac larvae	Juveniles
Destruction of organisms by nets	H	H	L	L
Escape through nets	L	L → M	M → L	L
Unavailability to nets	M - H	M - H	M → L → M	M
Orientation to bottom in relation to flow ^c	L	L	L → M	H
Active net avoidance	L	L	M	H

^aSee text for further explanation.^bH = high potential, L = no or low potential, and M = moderate potential.^cAssuming tows are always made against the direction of water flow.

(V-189)

(a) Destruction of Organisms by Nets

Organisms entering the mouth of a net will usually not move directly into the collecting bottle at the end of the cone, but will rather move down the mesh walls or be retained against the walls until the net is washed down prior to removal of the sample. If the filtration pressure through the net is high enough, fragile organisms can burst, and may be retained on the net in spite of washing, pass through the net, or (in the case of late striped bass eggs) be misidentified as yolk-sac larvae.⁵⁴ Filtration pressure through the net increases as the open area of the mesh in relation to the mouth opening (the "open-area ratio") decreases, and it increases as the square of the towing velocity. Destruction of dyed striped bass eggs in fixed nets at the Indian Point discharge canal, with relative water velocities lower than those generally used in river sampling, has been documented,⁴⁶ and similar destruction of yolk-sac larvae is an important possibility. Clogging of nets by algae and detritus⁹⁶ could contribute to this phenomenon by decreasing the open area of the mesh.

(b) Escape through Nets

This possibility depends on the relationship between the size of the organisms, the size of the mesh, and the uniformity of the mesh size. Passage of young post yolk-sac larvae through nets with a mesh opening of approximately 508 x 787 μm was suspected in the HRFI study,⁹⁶ and could possibly occur to some extent with the 500 x 500 μm (and larger) nets which were used to sample this stage in 1973.

(c) Unavailability to Nets

Striped bass eggs are slightly more dense than fresh water and, in the absence of sufficient turbulence, may settle to the bottom of the water column.¹⁰¹ The TI study ^{54,59,97,98} indicates a tendency for both eggs and yolk-sac larvae to be more concentrated near the bottom of the Hudson. The gear that has been used to date is not capable of sampling the lower foot or so of the river and even the epibenthic sled used in 1973 may ride off the bottom some (and perhaps most) of the time. The unavailability of eggs and yolk-sac larvae to the nets is likely to be a more significant phenomenon in the 1967 than in the 1973 data.

Post yolk-sac larvae have increasing mobility with age and appear to migrate vertically in the water column and thus are likely to be more available to sampling gear. Older larvae, and particularly juveniles, become increasingly bottom-oriented and tend to move to shoal areas, where they could again be relatively unavailable even to the epibenthic sled.

(V-190)

(d) Orientation to Bottom in Relation to Flow

For the most part, late larval and juvenile striped bass, once in shoal areas, are thought to be able to resist passive transport with the water. If they are stationary with respect to the bottom, the number of young stripers potentially encountered by a net being towed at a fixed velocity relative to the water will be lower if the tow is made against the current (in effect, the fish will be swimming in the same direction as the net is being towed).

With the exception of the 1973 "ichthyoplankton river survey" and "shoal survey" by Texas Instruments,⁵⁴ ichthyoplankton nets, trawls, and sleds in 1967 and 1973 were either towed against the tide or the direction of tow was not specified. Investigation of the importance of this source of error is highly desirable.

(e) Active Net Avoidance

This general heading incorporates a number of interactions among the sensory abilities and behavioral characteristics of planktonic and nektonic organisms, the design and use of gear intended to capture them, and the prevailing physical characteristics of the local environment. An overview of the subject can be found in Chap. 4 of Ref. 100.

The biological aspects of net avoidance are related to the ability of organisms to detect and respond to some change associated with the approach of the net. Clutter and Anraku⁵³ make the interesting

observation that "zooplankton can move in any direction relative to the trajectory of a sampling device and still disperse away from the path of the device so long as a gradient in intensity of the cue, or of the reaction to it, occurs in the vicinity of the trajectory. But avoidance will be increased if the animals are capable of oriented movement away from the trajectory."

Even striped bass yolk-sac larvae have some (albeit quite limited) swimming ability. Swimming ability (speed) should progressively increase as young post yolk-sac larvae grow through the juvenile stage. With respect to sensory ability, it seems likely that visual acuity and intensity discrimination, the sophistication of the lateral line system, the sensitivity of inner-ear organs to angular acceleration, and hearing ability would all increase with increasing age. All but the last of these would potentially allow localization of and directed response to a disturbance. Phenomena associated with shoaling behavior could also increase avoidance. Obviously, the condition of the organism affects avoidance ability and may be a significant factor in comparing samples taken in power plant discharge canals with those taken at the intakes or in the river.⁴⁶

(V-191)

Physical conditions clearly can influence the ability of fish to avoid nets. The most obvious variable is light, which varies diurnally and with depth, depending on turbidity. This makes the determination of diurnal vertical migrations by organisms that can see and avoid nets quite difficult. Temperature is another physical variable which likely affects avoidance because of its effect on swimming potential.

Given these biological and physical factors, the choice and method of use of sampling gear can affect the subsequent population estimates. Tows made at night or in deep water can be expected to yield higher catches of older organisms, assuming even distribution. Minimizing the acceleration fronts ahead of nets — by eliminating, where practicable, towing cables and flowmeters, minimizing disturbances caused by the frame, and increasing the open-area ratio and, where appropriate, the mesh size — should reduce avoidance. Similarly, the use of large nets and high towing speeds is thought to reduce avoidance by, respectively, increasing the average distance organisms must move to avoid the net and decreasing the available evasion time.⁵³ Clearly, trade-offs are involved in the use of some of these techniques.

(f) Other Sources of Error

Two additional sources of error related to the sampling gear have not been listed in Table V-27, because they do not necessarily differentially affect estimates of abundance of the various stages. The first is flowmeter precision and accuracy. Examination of the raw data in Refs. 59 and 97 indicates that this factor could be important in affecting estimates of both relative distribution and absolute abundance of ichthyoplankton; the staff has little information on which to base an evaluation of this source of error. The second source is gear failure, which apparently resulted in the failure to sample a few regions or strata of the river during some of the weekly river runs in 1973.

References for Section 5.4.3.1
(from material excerpted in IP3 FES)

46. New York University, Institute of Environmental Medicine, "Hudson River Ecosystem Studies, Effects of Entrainment by the Indian Point Power Plant on Biota in the Hudson River Estuary, Progress Report for 1973," prepared for Consolidated Edison Company of New York, Inc., September 1974.
53. Clutter, R. I., and M. Anraku, "Avoidance of Samplers," *Monogr. Oceanogr. Methodology* 2: 57-76, 1968.
54. Texas Instruments, Incorporated, Services Group, "Fisheries Survey of the Hudson River, March-December 1973," vol. IV (Draft), prepared for Consolidated Edison Company of New York, Inc., September 1974.
59. Texas Instruments, Incorporated, Services Group, "1973 Hudson River Program, Fisheries Data Summary, May-July," vol. I, prepared for Consolidated Edison Company of New York, Inc., October 1973.
96. Hudson River Policy Committee, "Hudson River Fisheries Investigations, 1965-1968, Evaluations of a Proposed Pumped-Storage Project at Cornwall, New York, in Relation of Fish in the Hudson River," presented to Consolidated Edison Company of New York, Inc., 1968.
97. Texas Instruments, Incorporated, Services Group, "1973 Hudson River Program, Fisheries Data Summary, July-November," vol. II, prepared for Consolidated Edison Company of New York, Inc., December 31, 1973.
98. Texas Instruments, Incorporated, Services Group, "Fisheries Survey of the Hudson River, March-July 1973," vol. III, prepared for Consolidated Edison Company of New York, Inc., March 1974.
100. UNESCO, "Zooplankton Sampling," *Monogr. Oceanogr. Methodology* 2; 174 pp., 1968.
101. Talbot, G. B., "Estuarine Environmental Requirements and Limiting Factors for Striped Bass," American Fisheries Society Special Publication No. 3, pp. 37-49, 1966.

In model runs, the ORNL staff has continued to use values of 0.5 and 1.0 for f_I . The new information appears consistent with this practice, although the information from the 1974 sampling at Bowline (analysis of which was completed after the model runs were done) suggests that it is appropriate to consider a lower f_I factor for young larvae at this plant relative to the other plants. It is possible that information which became available after March 1976 (not considered in connection with f_I in this report) will provide further useful information about f_I values.

References for Section 5.4

1. New York University, Institute of Environmental Medicine, *Hudson River Ecosystem Studies, Effects of Entrainment by the Indian Point Power Plant on Biota in the Hudson River Estuary, Progress Report for 1973*, prepared for Consolidated Edison Company of New York, Inc., September 1974.
2. New York University, Institute of Environmental Medicine, *Hudson River Ecosystem Studies, Effects of Entrainment by the Indian Point Power Plant on Biota in the Hudson River Estuary. Addenda to the 1973 Report. I. An Analysis of the Abundance of Four Life History Stages of Striped Bass Collected in the Intakes and Discharge Canal of Indian Point Unit I and in the Hudson River at Indian Point. II. Larval Striped Bass Length Frequency Analysis*, prepared for Consolidated Edison Company of New York, Inc., August 1976.
3. New York University, Institute of Environmental Medicine, *Hudson River Ecosystem Studies, Effects of Entrainment by the Indian Point Power Plant on Biota in the Hudson River Estuary, Progress Report for 1974*, prepared for Consolidated Edison Company of New York, Inc., February 1976.
4. New York University, Institute of Environmental Medicine, *Mortality of Striped Bass Eggs and Larvae in Nets*, special report to Consolidated Edison Company of New York, Inc., July 1976.
5. Lawler, Matusky, and Skelly Engineers, *1974 Hudson River Aquatic Ecology Studies - Bowline Point and Lovett Generating Stations*, prepared for Orange and Rockland Utilities, Inc., December 1975.

5.5 Striped Bass Impingement

The two objectives of this section are (1) to summarize and discuss all available estimates of striped bass collection rates (i.e., number of fish collected per unit volume of water taken into a power plant) by month for each of the power plants along the Hudson River and (2) to forecast the number of striped bass expected to be impinged with once-through cooling or with closed-cycle cooling at Bowline, Roseton, and Indian Point Units 2 and 3.

5.5.1 Summary and discussion of striped bass collection rates

Monthly estimates of collection rates have been calculated as total number of striped bass collected during the month divided by the total volume of water withdrawn by the power plant during the sampling periods in that month. Texas Instruments (ref. 1, Appendix F) has compared this usual estimator of collection rate with three other estimators. They conclude that "the difference between estimates by any of the four methods appears extremely small when compared with the size of the standard errors of each estimate" (ref. 1, p. F-12). ORNL has selected the "usual ratio" estimator because it is straightforward to calculate and because an estimator that considered circulator flow rate was required to forecast the number of striped bass impinged with once-through cooling and with closed-cycle cooling at Bowline, Roseton, and Indian Point Units 2 and 3.

5.5.1.1 Collection rates. Striped bass collection rates are summarized in Table 5.5.1. Comparable tables are given in Appendix E of this report for alewife, bay anchovy, blueback herring, tomcod, and white perch.

Table 5.5.1 covers the period June 1972 through December 1975 and includes estimates of monthly collection rate for all months for which ORNL was able to find the necessary data. Where there are conflicting estimates, an appropriate footnote has been included, and in some cases, two estimates are presented. These conflicts should be resolved by the appropriate utility as soon as possible. Also, Orange and Rockland (Bowline and Lovett), Central Hudson (Roseton and Danskammer), and Niagara Mohawk (Albany) or their contractor (Lawler, Matusky, and Skelly Engineers) have data that have not been made available in reports but that would permit filling in numerous blanks that presently exist in the table. The value of this type of multiyear and multiplant tabulation of monthly collection rates for striped bass is illustrated and discussed in Sects. 5.5.1.2, 5.5.1.4, and 5.5.2.

5.5.1.2 Collection efficiency. Not all of the fish killed by impingement at a power plant are actually collected. However, none of the estimates in Table 5.5.1 include a correction for collection efficiency. A study to estimate the efficiency of collection procedures has been performed at Indian Point by Texas Instruments, but apparently

Table 5.5.1. Summary of available estimates of monthly collection rates for striped bass for the power plants along the Hudson River for the years 1972 through 1975^a

Year	Month	Bowline	Lovett	Indian Point			Roseton	Danskammer		Albany
				Unit 1	Unit 2	Unit 3		Units 1 and 2	Units 3 and 4	
1972	June			1	0					
	July			1						
	August			11						
	September			13	1					
	October			11	3					
	November			7						
	December			5						
1973	January	28.3	3.12	0	93			0.00	0.00	
	February	52.2	8.21		10			1.27	1.71	
	March	19.2	13.2		11			0.00	0.00	
	April	36.1	16.8		15			0.00	0.00	
	May	9.47	0.37	0	0			6.68	0.40	
	June	0.00	4.25	2	1			9.81	11.5	
	July	4.36	1.83		0			51.7	17.2	
	August	3.96	18.3	0	3			35.6	12.2	
	September	1.18	4.71	0	0			60.0	23.4	
	October	1.19	3.26		0			712.	45.1	
	November	4.59	21.0	5	7			239.	24.3	
	December	26.2	27.9	7	12			77.9	25.0	
1974	January	51.9	78.7	8	34		0.40	11.5	3.01	
	February	260	89.9	3	35			3.25	0.00	
	March	141		5	9	7	0.0	0.00	0.00	
	April		62.1	11	7	5	0.29	26.2(22.4)	2.22	0.19
	May	16.5	5.48	2	10	4	2.09 ^b	14.4(11.5)	6.50(3.44)	12.5
	June	0.63	7.21	1	2	5	1.66 ^b	40.0 ^b (41.1)	6.66	133
	July	1.87	1.85	2	3	4	0.71 ^b	99.5	18.8 ^b	89.9
	August	1.40	4.25	2	5	2	0.98 ^b	56.6	16.0	63.9

Table 5.5.1 (continued)

Year	Month	Bowline	Lovett	Indian Point			Roseton	Danskammer		Albany
				Unit 1	Unit 2	Unit 3		Units 1 and 2	Units 3 and 4	
1975	September	2.33	3.28	2	4	2	1.00 ^b	39.2	8.22	44.2
	October	19.8	12.8	3	2	4	1.82 ^b	16.9	5.86	15.6
	November	26.2	9.0	3	4		6.00 ^b	15.6	2.01	2.67
	December	115.	12.2	16	5		0.82 ^b	30.5	3.67	0.06
	January	267.	39.6	20	5		0.92	5.79	0.98	0.0
	February	66.0	23.8	105	16		0.18	4.83	0.53	0.0
	March	161.	26.4	12	2		0.29	4.36	1.11	0.0
	April	380.	42.3	12	8					
	May	2.64	c	1	1					
	June	c	2.64	0	0					
	July	2.64	2.64	3	13					
	August	c	7.93	3	13					
	September	c	5.28		7					
	October	c	2.64		4					
	November	c	15.9		2					
	December	87.2	13.2		4					

^aUnits for collection rate are number of fish per million cubic meters of power plant intake flow. Y (number/ 10^6 m³) = 264.17 (gal/m³) $\times$ (number/ 10^6 gal). For the period January through September 1974, two sources of data are available for each power plant, giving number of impinged fish collected during the month and the volume of water withdrawn by the power plant during the collection periods for that month. Estimates of collection rate were calculated from each of the two sets of data; if the two results differed by 1.0 fish/ 10^6 m³ or more, both estimates were recorded in the table. In all such cases, the second entry (i.e., the one in parentheses) is based on data from ref. 1.

^bTwo conflicting estimates of power plant intake flow were provided; the estimate that appeared most likely to be correct was used.

^cLess than 2.64 fish/ 10^6 m³.

Sources relied on in preparing Table 5.5.1 are as follows:

Bowline

January 1973 - September 1974:	ref. 1, vol. II, Appendix F, Tables F-13 and F-14
January 1975 - December 1975:	ref. 2, Tables VIII-32 to VIII-36, and VIII-38
January 1974 - December 1974:	ref. 9, Table X-28 (white perch only)
October 1974 - December 1974:	ref. 9, Appendix X.A-1 (all species except white perch)

Lovett

January 1973 - September 1974:	ref. 1, vol. II, Appendix F, Tables F-5 to F-12
January 1975 - December 1975:	ref. 2, Tables VIII-42 to VIII-47
January 1974 - December 1974:	ref. 9, Table X-29 (white perch only)
October 1974 - December 1974:	ref. 9, Appendix X.A-2 (all species except white perch)

Indian Point

June 1972 - December 1973:	ref. 3, Tables A-3.5 to A-3.8
January 1974 - December 1974:	ref. 4, Tables B-5 to B-7
January 1975 - December 1975:	ref. 5, Tables A-6 and A-7

Roseton

July 1974 - September 1974:	ref. 1, vol. II, Appendix F, Table F-19
January 1974 - December 1974:	ref. 6
January 1975 - March 1975:	ref. 7

Danskammer

January 1973 - September 1974:	ref. 1, vol. II, Appendix F, Tables F-15 to F-18
January 1974 - December 1974:	ref. 6
January 1975 - March 1975:	ref. 7

Albany

January 1974 - April 1974 - March 1975:	ref. 8, Tables 2 and 4
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References for Table 5.5.1

1. Texas Instruments, Inc., *First Annual Report for the Multiplant Impact Study of the Hudson River Estuary*, prepared for Consolidated Edison Company of New York, Inc., vols. I and II, July 1975.
2. Lawler, Matusky, and Skelly Engineers, *1975 Hudson River Aquatic Ecology Studies - Bowline Point and Lovett Generating Stations*, prepared for Orange and Rockland Utilities, Inc., vol. I, April 1976.
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.
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.
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.
6. Lawler, Matusky, and Skelly Engineers, *Draft 1974 Hudson River Aquatic Ecology Studies at Roseton and Danskammer Point*, vol. I, 1976.
7. Letter of Transmittal for Impingement Data from January through March 1975 for Roseton and Danskammer Point Generating Stations, from Thomas Huggins, Central Hudson Gas and Electric Company, to Barbara Pastalove, U.S. Environmental Protection Agency, June 11, 1975.
8. Lawler, Matusky, and Skelly Engineers, *Albany Steam Electric Generating Station Impingement Survey (April 1974 through March 1975)*, prepared for Niagara Mohawk Power Corporation, June 1975.
9. Lawler, Matusky, and Skelly Engineers, *1974 Hudson River Aquatic Ecology Studies - Bowline Point and Lovett Generating Stations*, prepared for Orange and Rockland Utilities, Inc., vol. I, December 1975.

no comparable studies have been performed at either Bowline or Roseton. The highlights of the Texas Instruments study are quoted below (ref. 2, pp. III-9 through III-13).

Impingement collection efficiency tests indicated that a significant but variable bias may have existed in impingement estimates based on collections from the Unit 2 traveling screens. The mean recovery rate for 1975 tests with the air curtain on was 17%, ranging between 2% and 45% (Table [5.5.2]); the 1974 mean was 12% with the air curtain on.

No consistent effect of screen location was indicated by statistical analysis of these experimental results. The variability of screen-location effect on impingement in the 2 years was apparent from results of chi-square tests: one test was not significant ($\alpha = 0.05$) and two demonstrated significantly higher efficiency at end screens. On the other hand, interior screens recovered significantly more impinged fish than did end screens during 1974 tests.

The Mann-Whitney test indicated no significant difference ($\alpha = 0.10$) between efficiencies at 60% and 100% flow rate for combined 1974 and 1975 data. Because of variable screen differences, screens were not combined; only screen 25, where sufficient data existed, was used in the Mann-Whitney test.

Experiments verified the assumption that test organisms were impinged although the exact proportion of released fish could not be determined. The intake's structural design did not permit access for collection of marked fish from the water in front of the fixed screen when it was raised and not back-washed. Most of the dyed fish were observed on the screen as it was raised. The fish were distributed in the five patches on the screen at which they were released. As the point of impingement of the screen cleared the water surface, the fish often rolled off with debris and floated in front of adjacent screens, and some of the marked fish entered the forebay when the bottom edge of the screen was raised above the water surface.

Some fish were lost during fixed screen washing when water jets blew them back into the river and the air curtain was observed to have pushed some of the fish removed during fixed-screen washings back into the river. Based upon visual observations, the air curtain may have actively removed fish from the fixed screen and carried them into the river. Fish thus removed are either carried away by the river, impinged on the same or adjacent screens, or taken by scavenging sea gulls. The probability of reimpingement depended, in part, on screen location and tidal stage when the fish were removed from the fixed screens. Fish removed from screen 21 during

Table 5.5.2. Results of collection efficiency tests conducted at Indian Point Unit 2 (air curtain on) during 1975

Date (1975)	Screen	Number recovered from all screens	Number lost	Percent recovered
June 19	22	15	135	10.00
	25	12	138	8.00
June 23	22	30	120	20.00
	25	15	135	10.00
September 10	21	68	82	45.33
	25	37	113	24.67
October 1	22	3	147	2.00
	26	24	126	16.00
Mean				17.00

ebb tide, for example, were not exposed to adjacent circulator flow and could have been carried away by river flow; fish removed from fixed screen 25 could have been reimpinged at adjacent screens during any tidal stage. Since fish usually were recovered during several subsequent washes (within 3 days for most recovered fish), several tidal conditions and an array of other variables affected each test.

The results of this study, although indicating the potential for significant underestimation of impingement magnitude, especially during air-curtain operation, are preliminary and should not be used to quantify such bias or to compute correction factors for impingement counts. The results obtained during 1974 and 1975 indicate that recovery rates are highly variable between screens and tests due to the uncontrollable variables. It will therefore be necessary to determine several correction factors blocked on groups of variables in order to reflect these differences. In order to establish correction factors accounting for the variability observed, more tests are necessary to determine the confidence intervals for efficiency estimates and to determine those variables which affect collection efficiency. It should be noted that in addition to an efficiency correction, the survival of impinged fish lost before collection should also be taken into account.

ORNL does not agree with the statement in the TI report that the results of the efficiency tests "should not be used to quantify such bias or to compute correction factors for impingement counts." This statement is both ludicrous and self-serving for Consolidated Edison.

The results obtained by Texas Instruments are presented in Table 5.5.2. The mean of 17% efficiency for 1975 compares with a mean of 12% efficiency for 1974, in both cases with the air curtain on. Admittedly, the variability is considerable; in fact, for 1975 the coefficient of variation is 79%, and the 95% confidence interval is 6 to 28% efficiency. While it would be desirable to reduce the range of uncertainty even further, the TI studies have already greatly reduced the original range of uncertainty (percent efficiency between 0 and 100%). Thus the number of fish actually collected at Indian Point Unit 2 relative to the number impinged is probably low by a factor of 4 to 15 when the air curtain is operating.

Texas Instruments has estimated collection efficiency at Indian Point Unit 2 using what appears to be a reasonable and generally applicable methodology. In ORNL's judgment, comparable efficiency tests should be performed at Bowline, Lovett, Indian Point Unit 2 (without air curtains), Indian Point Unit 3, Roseton, Danskammer, and Albany as soon as possible. Until plant-specific estimates of collection efficiency are available, it will not be possible to take full advantage of the information in a table such as Table 5.5.1. It is ORNL's opinion that the regular and conscientious monitoring of the monthly impingement rate of striped bass

and of other fish species at all the power plants from Bowline to Albany can provide an invaluable time series of the status of the Hudson River striped bass population (and of other fish populations). The cost of collecting the necessary data is trivial compared to the cost of any alternative sampling program that would provide data of comparable quantity and quality.

5.5.1.3 Impingement survival. The survival of impinged fish lost before collection should be taken into account in arriving at a more accurate and realistic estimate of impingement rate. Impingement survival studies were performed by Ecological Analysts in 1975 at Bowline, Lovett, Roseton, and Danskammer. Only the results from the Roseton study were available as of January 1, 1977. The highlights of these results are quoted below (ref. 3, pp. 3-4 through 3-9).

3.3 RESULTS

Impingement survival sampling performed at the Roseton Generating Station in the fall of 1975 yielded primarily young-of-the-year anadromous fish species. The most abundant species, in order of decreasing abundance, were blueback herring, white perch, alewife, and striped bass, with blueback herring and white perch comprising more than 90 percent of the collections. Young centrarchids (sunfishes) were the most abundant resident fish species collected. Survival of the fish collected was highly dependent on the screen-wash mode of operation. Data indicate that a progressively lower probability of survival exists with those operational modes of increasing holding times between screen washings. Maximum survival was apparent with continuous operation of the traveling screens. However, sufficient sample size for comparisons involving continuous traveling-screen operations was only available for white perch. Initial and 96-hour latent survival of white perch was significantly higher with continuous washing than with washing after two hours of holding. Initial survival with 2-hour washing was significantly higher than that for 4- or 6-hour washing regimes. White perch collected by beach seines from the Hudson River and held in the holding facilities for 96 hours generally maintained survival at or near 100 percent. The survival curve for 96 hours for white perch for the continuous washing regime is depicted in Figure [5.5.1].

3.4 DISCUSSION

The impingement survival studies performed during the fall represent only one phase of the overall impingement phenomena at the Roseton plant. The fall phase represents the period in which young-of-the-year anadromous species migrate downstream past Roseton and other plants on the Hudson River on

Fig. 5.5.1. Latent survival of white perch (N = 201) impinged at the Roseton Generating Station under the continuous traveling screen washing mode during the fall of 1975. Source: Ecological Analysts, Inc., "Roseton Generating Station Impingement and Entrainment Survival Studies, 1975 Annual Report," prepared for Central Hudson Gas and Electric Co., December 1976, Fig. 3.3-1.

their way to the lower estuary, Long Island Sound, and the Atlantic Ocean. Another phase which occurs from late December through February includes the spawning migration of the Atlantic tomcod. The third phase is the spring phase (mid-April to mid-June) which encompasses the spawning migration of white perch. These three phases represent the periods in which most of the yearly impingement at Roseton occurs. Only the white perch and blueback herring juveniles appear numerous in fall impingement collections at Roseton. This may be somewhat related to their relative abundance and distribution in the river. Survival potential of the young of these two species from screen washing and return to the river appears to be low. However, somewhat improved survival is indicated with continuous operation of the traveling screens. Similar results were obtained during the fall of 1975 at the Danskammer Point plant located less than 1.5 km upriver of Roseton (EA 1976). Despite the high percent initial survival for white perch at continuous washing (83 percent), poor latent survival (8 percent) strongly indicates a weakened, stressed, or damaged condition. Such a condition may be a result of the impingement process or some factor prior to impingement. Evidence collected at the Indian Point nuclear plant indicates that intakes may act to some extent as a selective predator or scavenger, taking in a proportion of stressed or dying fish (Consolidated Edison Company of New York 1974; Texas Instruments 1973). Latent survival may also be low due to the synergistic effect of impingement and latent holding. Survival would probably be somewhat higher if fish were not held and observed.

Impingement survival during the winter Atlantic tomcod and spring white perch seasons is currently (1976) being monitored by Ecological Analysts, Inc. Preliminary impingement survival during the 1975 Atlantic tomcod spawning season at Roseton (Lawler, Matusky & Skelly 1976), indicates high (78 percent) initial survival of fish early in the spawning season. Survival declined during the post-spawning period.

REFERENCES FOR THE EXCERPT

"The Biological Effects of Fish Impingement on the Intake Screens at Indian Point," Appendix BB, IP3 ER, Jan. 15, 1973.

Ecological Analysts, Inc., 1975 *Danskammer Point Generating Station Impingement and Entrainment Survival Studies, Annual Report*, vol. 1, prepared for Central Hudson Gas and Electric Company, July 1, 1976.

Lawler, Matusky, and Skelly Engineers, Draft Report to Central Hudson Gas and Electric Company for 1975 Impingement and Entrainment Studies, 1976.

Texas Instruments, Inc., *Hudson River Ecological Study in the Area of Indian Point. First Annual Report to Consolidated Edison Company of New York, Inc.*, 1973.

ORNL's position is that, given the present mode of operation with the intake screens (noncontinuous operation of traveling screens at Bowline, Roseton, and Indian Point Unit 3; fixed screens at Indian Point Unit 2, with a high-pressure water spray to clean the screens) and given the EA results to date at Roseton³ and TI results at Indian Point,^{2,4,5} latent survival of impinged striped bass at any of the plants appears to be low. For the purposes of subsequent analysis in this section and of model runs discussed in Sect. 5.8, impingement survival is assumed to be zero under all conditions at all power plants, including Cornwall.

5.5.1.4 Temporal pattern of collection. The temporal pattern of collection rates for striped bass is given in Table 5.5.3. For each power plant and for each year for which sufficient data were available (Table 5.5.1), the three to four months when the collection rate was highest and lowest are tabulated. This analysis does not depend on knowing the absolute number of fish impinged at each power plant and thus does not require any assumption about the unknown collection efficiencies (Sect. 5.5.1.2). For Bowline, Lovett, and Indian Point, collection rates tend to be high from December through April and low from May through October. The temporal pattern for Roseton, Danskammer, and Albany is somewhat different. Collection rates tend to be high from June through October or November and low from January through April. Further analysis of this difference in temporal pattern is necessary, but ORNL suspects that, in part, it is due to the downriver power plants impinging young-of-the-year striped bass during their first winter and upriver plants impinging yearling striped bass.

Table 5.5.3. Temporal pattern of collection rates for striped bass
 (The numbers in the body of the table represent month of the year, January being 1 and December being 12.
 The three to four months when the collection rate was highest and lowest are tabulated for each
 power plant (or unit), if data were available)

Year	Bowline Point	Lovett	Indian Point 1	Indian Point 2	Indian Point 3	Roseton	Danskammer 1 and 2	Danskammer 3 and 4	Albany
<u>High months</u>									
1973	1-2, 4, 12	4, 8, 11-12		1, 3-4, 12			9-12	9-12	
1974	1-3	1-2, 4	1, 3-4, 12	1-3, 5		5-6, 10-11	6-9	6-9	6-9
1975	1, 3-4, 12	1-4		2, 4, 7-8					
<u>Low months</u>									
1973	6, 8-10	1, 5, 7, 10		5, 7, 9-10			1-4	1, 3-5	
1974	6-9	5, 7-9	6-9	6-7, 9-11		1-4	1-3, 5	2-4, 11	1-3, 12
1975	6, 8-11	5, 7-8, 10		3, 5-6, 11					

5.5.2 Forecasts of annual number of striped bass impinged for various power plant configurations

The purpose of this section is to estimate the number of striped bass impinged annually at each power plant for seven different power plant configurations (Table 5.5.4). Configuration 1, with once-through cooling at Bowline, Indian Point, and Roseton, corresponds to the present situation. The other six configurations involve possible, but at present hypothetical, combinations of closed-cycle and once-through cooling, without and with the proposed Cornwall pump storage facility operating.

Table 5.5.4. Power plant cooling system configurations

(OT, once-through condenser cooling; CC, closed-cycle condenser cooling; - and + mean Cornwall pump-storage facility not operating or operating respectively)

Code	Bowline	Indian Point	Roseton	Cornwall
1	OT	OT	OT	-
2	CC	CC	CC	-
3	OT	OT	CC	-
4	OT	CC	OT	-
5	CC	OT	OT	-
6	OT	OT	OT	+
7	CC	CC	CC	+

Forecasts of the annual number of striped bass (primarily young of the year 2 in. to 4 in. in length) killed by impingement at all the power plants from Bowline to Albany, $\hat{N}$, have been calculated using the following equation:

$$\hat{N} = \sum_{i=1}^P \hat{N}_i, \quad (5.5-1)$$

where $\hat{N}_i$ is the estimated number of striped bass impinged annually at power plant i and P is the number of power plants. Then

$$\hat{N}_i = \sum_{j=1}^{12} (1 - s_i) a_i (1.0 - b_i) c_j d_{i,j} Y_i X_{i,j}, \quad (5.5-2)$$

where s_i is the probability of surviving impingement at power plant i , a_i is the inverse of the collection efficiency at power plant i , b_i is the fraction of time during a year that intake pumps at power plant i are

shut down for unscheduled reasons, c_j is the fraction of a year represented by month j , d_{ij} is the fraction of the maximum intake flow at power plant i for month j that is scheduled to be withdrawn, Y_i is the annual maximum intake flow (including service water) at power plant i (in units of $10^6 \text{ m}^3/\text{year}$), and X_{ij} is the average collection rate (number of striped bass collected per 10^6 m^3) at power plant i during month j .

In the following paragraphs, each of the parameters on the right side of Eq. (5.5-2) is discussed and values are given. Finally, values for $\hat{N}_i$ (Eq. 5.5-2) and $\hat{N}$ (Eq. 5.5-1) are presented for each of seven power plant configurations.

In accord with the discussion in Sect. 5.5.1.3, the probability of surviving impingement, s_i , is taken to be zero under all conditions at all power plants.

To forecast even the relative total number of striped bass impinged (as opposed to collected) at all the power plants requires that some assumption be made about the unknown collection efficiencies (Sect. 5.5.1.2). ORNL has assumed that (1) although unknown, the collection efficiency is the same under all conditions at all plants and (2) until additional data become available, an estimate for collection efficiency of 0.5 is appropriate. One problem with the first assumption is that collection efficiency is undoubtedly negatively related to the magnitude of water currents at right angles to the plane of the intake screens. Such currents are more pronounced at Roseton and Indian Point than at Bowline, which withdraws water from Bowline Pond.

The basis for selecting a collection efficiency of 0.5 in the second assumption is as follows. The TI mean estimate of 0.17 for collection efficiency at Indian Point Unit 2 is based on data obtained with the air curtains operating (see Table 5.5.2). A judgment shared by TI and ORNL is that the air curtain probably appreciably decreases collection efficiency. Given this situation, a reasonable middle ground seems to be to adopt a value of 0.5 until additional data become available. Thus, a_i in Eq. (5.5-2) equals 2.0 for all power plants i .

The fraction of time during a year that intake pumps at power plant i are shut down for unscheduled reasons, b_i , is taken to be 0.1 for all plants. Evidence in support of b_i values greater than 0.0 is provided by Texas Instruments (ref. 1, Appendix E, Tables E-1 to E-12), where estimates of actual plant intake flow are given as a percent of the maximum possible intake flow over the period May through mid-July for 1973 and 1974 at various units at Bowline, Lovett, Indian Point, and Danskammer. These approximate values of $1.0 - b_i$ range from 0.304 to 0.853. A detailed justification by utility companies of more realistic b_i values may be appropriate. Care must be taken to estimate b_i values based on actual vs scheduled plant intake flows (including service water), as opposed to power output, because water pumps frequently are scheduled to operate even when the plant is not producing electricity.

The fraction of a year represented by month j , c_j , has been approximated as a constant for all months as $1/12 = 0.08333$.

Values for the fraction of the maximum intake flow at power plant i for month j that is scheduled to be withdrawn, $d_{i,j}$, are given in Table 5.5.5. The technical basis for incorporating the $d_{i,j}$ term in Eq. (5.5-2) is that certain plants schedule to operate intake pumps at reduced flow during certain months of the year. For example, 40% of the once-through condenser cooling intake flow is required to be recirculated at Indian Point when intake water temperature is 40°F or below. ORNL has assumed, for purposes of the present analysis, that the once-through condenser cooling flow is reduced to 60% of full flow from November through March (see Table 5.5.5). Roseton also apparently operates intake pumps at reduced flow during winter months (F. Dooris, personal communication), and Bowline appears to have a similar capability. Based on this information, ORNL has assumed for purposes of the present analysis that the maximum intake flow at both Roseton and Bowline is reduced to 75% from November through March (see Table 5.5.5).

Total annual maximum intake flow, Y_i , at power plant i is given in Table 5.5.6 for each of seven power plant configurations.

Cubic miles per day are the units required for inputting power plant intake flow to the Lawler, Matusky & Skelly striped bass model (see Sect. 5.8). The factor 0.9 is used because of the factor $1.0 - b_i$ in Eq. (5.5-2) and the choice of 0.1 as the value for b_i .

Note that the product $(1.0 - b_i)c_j d_{i,j} Y_i$ in Eq. (5.5-2) is an estimate of the actual intake flow at power plant i during month j . Both unscheduled and essentially random shutdowns of intake pumps, b_i , as well as scheduled reductions in intake flow, $d_{i,j}$, are taken into consideration.

Average collection rates, $X_{i,j}$, at power plant i during month j are given in Table 5.5.7. These values were calculated from the values in Table 5.5.1 by averaging over years. As a result, some averages are based on data for a single year (e.g., Roseton for April through December), while other averages are based on data for as many as four years (e.g., Indian Point Unit 2 for June, September, and October).

Implicit in Eq. (5.5-2) is the assumption that impingement is directly proportional to intake flow. In fact, this assumption is not likely to be strictly true because approach velocity is undoubtedly of some importance in determining impingement. Present opinion, however, is that flow is the more important of the two variables (ref. 6, p. V-6).

Estimates of the number of striped bass impinged annually at each power plant for each of seven power plant configurations are given in Table 5.5.8. Each J2 value was obtained using Eq. (5.5-2) with $j = 7$ to 11, i.e., July through November. Each J3 value was obtained using Eq. (5.5-2) with $j = 1$ to 6 and 12, i.e., January through June, plus

Table 5.5.5. Values for the fraction of the maximum intake flow at power plant i for month j that is scheduled to be withdrawn [$d_{i,j}$ values in Eq. (5.5-2)]

Plant	Method of cooling ^a	
Bowline	OT	1.0, April-October; 0.75, November-March ^b
	CC	1.0, January-December
Lovett	OT	1.0, January-December
Indian Point	OT	1.0, April-October; 0.614, November-March ^b
	CC	1.0, January-December
Roseton	OT	1.0, April-October; 0.75, November-March ^b
	CC	1.0, January-December
Danskammer	OT	1.0, January-December
Albany	OT	1.0, January-December
Cornwall ^c	OT	0.867 (January); 0.917 (February); 0.937 (March); 0.966 (April); 0.754 (May); 1.00 (June); 0.876 (July); 0.938 (August); 0.991 (September); 0.899 (October); 1.00 (November); 0.968 (December)

^a OT = once-through condenser cooling; CC = closed-cycle condenser cooling.

^b At Bowline and Roseton, the service water pumps withdraw water after the water has passed through the condenser cooling water pumps. At Indian Point, the service water pumps withdraw water directly from the river. The requirement at Indian Point to recirculate 40% of the intake flow applies only to the condenser cooling water pumps. Thus, $(0.60 \times 840,000 + 30,000) / 870,000 = 0.614$. The same $d_{i,j}$ value holds for both Indian Point Units 2 and 3.

^c The monthly $d_{i,j}$ values for Cornwall are calculated from the 1992 values in Lawler, Matusky, and Skelly Engineers, 1974 *Hudson River Aquatic Ecology Studies - Bowline Point and Lovett Generating Stations*, prepared for Orange and Rockland Utilities, Inc., vol. I, December 1975, Table 11, entitled "Projected Monthly Average Cornwall Pumping Flow Rates" (supplied by Consolidated Edison Company of New York to Lawler, Matusky, and Skelly Engineers, May 1974, and presented by J. P. Lawler, "Effect of Entrainment and Impingement at Cornwall on the Hudson River Striped Bass Population," Testimony before the Federal Power Commission in the Matter of Consolidated Edison Company of New York, Inc., Project No. 2338 (Cornwall), October 1974).

Table 5.5.6. Total annual maximum intake flow by power plant for each
of seven power plant configurations
[Y_i values in Eq. (5.5-2)]

Configuration	Bowline ^a	Lovett ^a	Indian Point ^a	Roseton ^a	Danskammer ^a	Albany ^a	Cornwall ^a
1	768,000 (1528)	228,051 (454)	1,740,000 (3462)	641,000 (1275)	232,000 (462)	359,500 (715)	
2	16,000 (31.8)	228,051 (454)	117,000 (233)	24,000 (47.8)	232,000 (462)	359,500 (715)	
3	768,000 (1528)	228,051 (454)	1,740,000 (3462)	24,000 (47.8)	232,000 (462)	359,500 (715)	
4	768,000 (1528)	228,051 (454)	117,000 (233)	641,000 (1275)	232,000 (462)	359,500 (715)	
5	16,000 (31.8)	228,051 (454)	1,740,000 (3462)	641,000 (1275)	232,000 (462)	359,500 (715)	
6	768,000 (1528)	228,051 (454)	1,740,000 (3462)	641,000 (1275)	232,000 (462)	359,500 (715)	2,402,603 (4780)
7	16,000 (31.8)	228,051 (454)	117,000 (233)	24,000 (47.8)	232,000 (462)	359,500 (715)	2,402,603 (4780)

Table 5.5.6 (continued)

Configuration	Total ^b	Segment 7 ^b	Segment 8 ^b	Segment 9 ^b	Segment 10 ^b
1	3,609,051 (0.0042478)	873,000 (C.0010275)		1,968,051 (0.0023164)	768,000 (0.0009039)
2	617,051 (0.0007263)	256,000 (C.0003013)		345,051 (0.0004061)	16,000 (0.0000188)
3	2,922,051 (0.0035216)	256,000 (C.0003013)		1,968,051 (0.0023164)	768,000 (0.0009039)
4	1,968,051 (0.0023376)	873,000 (C.0010275)		345,051 (0.0004061)	768,000 (0.0009039)
5	2,857,051 (0.0033627)	873,000 (C.0010275)		1,968,051 (0.0023164)	16,000 (0.0000188)
6	5,584,051 (0.0065724)	873,000 (C.0010275)	1,975,000 (.0023246)	1,968,051 (0.0023164)	768,000 (0.0009039)
7	2,592,051 (0.0030508)	256,000 (C.0003013)	1,975,000 (.0023246)	345,051 (0.0004061)	16,000 (0.0000188)

^aValues not in parentheses are flow rates, expressed in units of gallons per minute (gpm). Values in parentheses represent the maximum annual volume of water that could be withdrawn, in units of 10^6 m³ per year; they are calculated by multiplying the gpm values by 0.0019896, and they correspond to the V_i values in Eq. (5.5-2).

^bValues not in parentheses are expressed as gpm; values in parentheses are expressed as 0.9 cubic miles per day. Cubic miles per day are the units required for inputting power plant intake flow to the Lawler, Matusky & Skelly striped bass model (see Sect. 5.8). The factor 0.9 is used because of the factor $1.0 - b_i$ in Eq. (5.5-2) and the choice of 0.1 as the value for b_i .

Table 5.5.7. Average collection rates, $X_{t,j}$, for each month at Bowline, Lovett, Indian Point, Roseton, Danskammer, Albany, and Cornwall^{a,b}

Month	Bowline	Lovett	Indian Point	Roseton	Danskammer	Albany	Cornwall
January	116.	40.5	44.0	0.66	1.33	0.00	21.62
February	126.	40.6	20.3	0.18	0.75	0.00	15.46
March	107.	19.8	7.25	0.15	0.37	0.00	6.89
April	208.	40.4	8.75	0.29	1.11	0.19	12.64
May	9.54	2.39	3.75	2.09	2.69	12.5	2.73
June	0.65	4.70	1.60	1.66	9.08	133.0	4.26
July	2.96	2.11	5.00	0.77	18.0	89.9	6.47
August	2.23	10.16	5.75	0.98	14.1	63.9	7.75
September	1.61	4.42	2.80	1.00	15.81	44.2	6.01
October	7.44	6.23	2.60	1.82	25.5	15.6	9.04
November	10.7	15.3	4.33	6.00	13.2	2.67	9.71
December	76.1	17.8	7.00	0.82	14.3	0.06	9.98

^a Monthly values are in units of number of striped bass impinged per 10^6 m^3 of water withdrawn. Values are calculated from values in Table 5.5.1 by averaging over years. When there were two values for a given month, year, and power plant in Table 5.5.1, the average was used. Values in Table 5.5.1 denoted as being less than 2.64 striped bass per 10^6 m^3 were assigned a value of 1.32 striped bass per 10^6 m^3 in calculating the values for this table.

^b Rates for Lovett are based on data presented for the plant as a whole (five units), although in subsequent use of the values in this table only Lovett Units 4 and 5 are assumed to be operating. Rates for Indian Point are the average of the rates for Indian Point Units 2 and 3 in Table 5.5.1; in subsequent use of these average collection rates, Indian Point Unit 1 is assumed to be inoperative. Rates for Danskammer are based on data collected only at Units 3 and 4; rates for Units 1 and 2 are consistently higher than those for Units 3 and 4 (See Table 5.5.1), and in subsequent use of the average collection rates, only Danskammer Units 3 and 4 are assumed to be operating.

Table 5.5.8. Estimated number of striped bass impinged annually at each power plant for each of seven power plant configurations^a

(Values were calculated according to Eqs. (5.5-1) and (5.5-2), using values from Tables 5.5.1 and 5.5.5 - 5.5.7. Values are given for juvenile 2 (J2), juvenile 3 (J3), and J2 and J3 combined)

Configuration		Bowline	Lovett	Indian Point	Roseton	Danskammer	Albany	Cornwall	Total	Percent ^a
1	Total	128,187	13,920	42,135	2,767	8,055	38,827		233,891	100
	J2	5,103	2,602	9,767	1,735	6,002	23,195		48,404	
	J3	123,084	11,318	32,368	1,032	2,053	15,632		185,487	
2	Total	3,187	13,920	3,954	118	8,055	38,827		68,061	29
	J2	119	2,602	716	76	6,002	23,195		32,710	
	J3	3,068	11,318	3,238	42	2,053	15,632		35,351	
3	Total	128,187	13,920	42,135	118	8,055	38,827		231,242	99
	J2	5,103	2,602	9,767	76	6,002	23,195		46,745	
	J3	123,084	11,318	32,368	42	2,053	15,632		184,497	
4	Total	128,187	13,920	3,954	2,767	8,055	38,827		195,710	84
	J2	5,103	2,602	716	1,735	6,002	23,195		39,353	
	J3	123,084	11,318	3,238	1,032	2,053	15,632		156,357	
5	Total	3,187	13,920	42,135	2,767	8,055	38,827		108,891	47
	J2	119	2,602	9,767	1,735	6,002	23,195		43,420	
	J3	3,068	11,318	32,368	1,032	2,053	15,632		65,471	
6	Total	128,187	13,920	42,135	2,767	8,055	38,827	74,781	308,672	132
	J2	5,103	2,602	9,767	1,735	6,002	23,195	26,336	74,740	
	J3	123,084	11,318	32,368	1,032	2,053	15,632	48,445	233,932	
7	Total	3,187	13,920	3,954	118	8,055	38,827	74,781	142,842	61
	J2	119	2,602	716	76	6,002	23,195	26,336	59,046	
	J3	3,068	11,318	3,238	42	2,053	15,632	48,445	83,796	

^aPercent values for the various power-plant configurations are calculated relative to configuration 1.

December. Motivation for dividing the number of striped bass impinged annually into two groups follows from the formulation of the Lawler, Matusky & Skelly one-dimensional transport model (LMS 1-D model). Age class zero in the model is divided into five life stages. The last two of these stages, juvenile 2 (J2) and juvenile 3 (J3), are the impingeable stages. In a model run, striped bass start entering the J2 stage on approximately July 1 (May 1 plus the sum of the durations of the preceding three life stages, which is approximately 60 days). Striped bass entering the J2 stage are assumed to be 50 mm in length, where 50 mm is taken as the length below which a striped bass encountering the intake screen is more likely to be entrained than impinged and above which a striped bass is more likely to be impinged than entrained. November 30 is arbitrarily taken as the dividing date between J2 and J3. The end of the juvenile 3 stage in the model is taken to be April 30, after which survivors enter age class 1 and are called yearlings.

The correspondence between the above description of the J2 and J3 life stages in the LMS 1-D model and the division of impinged fish into two groups denoted J2 and J3 is only approximate. As indicated in Table A-9 of ref. 2 for Indian Point Unit 2 in 1975, young-of-the-year striped bass are impinged prior to July 1 and at lengths less than 50 mm. In addition, yearling striped bass are impinged during the J2 period of July through November. Finally, there are yearling striped bass impinged during May and June that do not fall in the model J2 and J3 periods but that are classified in the J3 period of December through April.

The values in Table 5.5.8 are subsequently used to calculate the estimated number of striped bass impinged annually by river segment, and these estimates, in turn, are used to calculate target values for the number of juvenile 2s and juvenile 3s to be impinged at each of the power plants in runs of the LMS 1-D model.

For present purposes, the percent values in the last column of Table 5.5.8 are of interest. With configuration 1 (i.e., once-through cooling at Bowline, Indian Point, and Roseton) as the reference, the number of striped bass impinged annually would be reduced to approximately 30% if closed-cycle cooling were installed at each of the above three plants. In addition, installing cooling towers at Roseton would probably be somewhat less effective in reducing impingement than installing cooling towers at Indian Point (99% vs 84%). As the values in the body of Table 5.5.8 indicate, impingement of striped bass appears to be more of a problem at Bowline than at either Indian Point or Roseton. Thus, as expected, installing cooling towers at Bowline (configuration 5) would be considerably more effective in reducing the number of striped bass impinged annually than installing closed-cycle cooling at either Indian Point (configuration 4) or Roseton (configuration 3).

References for Section 5.5

1. Texas Instruments, Inc., *First Annual Report for the Multiplant Impact Study of the Hudson River Estuary*, prepared for Consolidated Edison Company of New York, Inc., vols. I and II, July 1975.
2. 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.
3. Ecological Analysts, Inc., *Rooseton Generating Station Impingement and Entrainment Survival Studies, 1975 Annual Report*, prepared for Central Hudson Gas and Electric Co., December 1976, pp. 3-4 to 3-9.
4. 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.
5. 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.
6. J. Clark and W. Brownell, *Electric Power Plants in the Coastal Zone: Environmental Issues*, American Littoral Society Special Publication No. 7, October 1973.

5.6 Effects of Discharges

A summary of the assessment presented by ORNL in the IP3 FES, plus an update of that assessment in those areas where new information has become available, is given below, with particular reference to striped bass. Statements made with reference to Indian Point are, in general, valid for Bowline and Roseton.

5.6.1 Thermal

5.6.1.1 Oak Ridge National Laboratory (from IP3 FES, pp. V-107-V-110).

The staff's position is that the thermal discharge may increase river water temperatures to levels detrimental to aquatic biota in the vicinity of Indian Point. However, because the plume volume is an unbounded system and because of the lack of adequate biological data, the environmental effect cannot be quantified on an absolute scale (e.g., pounds per year) due to the discharges of water of above ambient temperatures at Indian Point. Nevertheless, the extent of adverse thermal effects (effects on survival, reproduction, and species composition, for example) would tend to be positively correlated with the volume of water within a specified isotherm and with the distance along the longitudinal axis of the Hudson River for which the predicted temperature exceeds specified ΔT 's....

The time of spawning for striped bass is dependent in part on temperature. However, adequate data are not available for the Hudson River, striped bass population to indicate the manner in which the longitudinal distribution of spawning varies as a function of the longitudinal temperature distribution or the rate of temperature increase in the spring. Calhoun, Woodhull, and Johnson⁵⁶ hypothesized that during a wet cold spring the striped bass in the San Francisco Bay estuary migrate farther upstream and out of the delta to spawn, while in years when the water warms up rapidly, most of the bass spawn in the delta and the lower part of the rivers. This hypothesis has been found to agree reasonably well with observations of spawning in the Sacramento River but only partly with observed spawning behavior in the San Joaquin River.⁵⁷

In expressing concern that the discharge of heated water by the Indian Point Units may result in a greater proportion of the annual production of fertilized eggs occurring in the vicinity of Indian Point, the staff has in mind not just the observable, near-field, thermal plume but also the far-field region affected by the thermal discharge from the Indian Point Plant and the Danskammer, Roseton, Lovett, and Bowline plants....

[See Sect. 3 of this report for an assessment of the potential multiplant thermal impact.]

Estimates of the percentage of the total Hudson River striped bass egg production produced within the "vicinity of Indian Point" can be made for [five] different years.

Year	Percentage between river miles 35 and 50
1955	30
1966	23
1967	10
1973	23
[1974]	[50]

The mean and range of the above estimates are [34.0]% and 10 to [50]% respectively....

From the point of view of striped bass or any other migrating fish species, the thermal discharge from the Indian Point Units is not likely to interfere with migration per se. However, the thermal discharges from the Indian Point, Danskammer, Roseton, Lovett, and Bowline plants may result in a downriver shift of the spawning distribution. The extent of this downriver shift will depend on the magnitude of the far-field temperature change and the relative importance of temperature in controlling extent of upriver migration and spawning.

If there were increased spawning of striped bass and subsequent hatching of fertilized eggs in the vicinity of Indian Point due to the thermal discharge from Indian Point, Danskammer, Roseton, Lovett, and Bowline, it still would not be possible with the present level of knowledge to predict a priori what effect this would have on the proportion of the total number of eggs spawned in the Hudson River that would survive through the first year of life. Variables that must be considered in assessing the possible effect include quality and quantity of food, number and type of predators, salinity, temperature, probability of entrainment, and probability of impingement. Each of these variables has a direct or indirect effect on the probability of survival of young-of-the-year. To determine how the probability of survival varies as a function of the thermal discharge from the Indian Point Plant, one must understand the dependence of upriver migration and spawning on temperature and the manner in which the variables given above, and thus probability of survival of young-of-the-year, vary longitudinally along the river. Such an analysis of a "wild" ecosystem⁶⁰ such as the Hudson River estuary, based on empirical data would be extremely difficult.

The subsequent influence on the size and age structure of the Hudson River, striped bass population would depend on the magnitude of the change in the probability of survival of the young-of-the-year.

One of the factors affecting the extent of impingement may be related to the existence in the wintertime of warmer river water in the vicinity of Indian Point Units Nos. 1, 2, and 3, particularly near the outfall, caused by the discharge of heated river water from the discharge canal. A related concern is cold shock following shutdown of a Unit in the winter. The applicant claims that, during the years of operation of Indian Point Unit No. 1, cold shock has not resulted in any discernible fish kill. The applicant recognizes that this has been a problem at other plants with other outfall designs, but it has not been a problem at Indian Point. Once all three [units] are operating, the potential for cold shock will be minimized because severe cold shock could only occur if all three [units] shut down simultaneously. Another point is that the high-velocity, submerged discharge assures rapid dilution so that the applicant does not anticipate that large areas of the river will be heated to [an extent] that could cause cold shock. The staff is in general agreement with this evaluation. Finally, the Technical Specifications limit the rate of temperature change for planned shutdowns, and the planned rate is 7 F°/hour in the discharge canal, which will result in a rate of change in the river of less than 1 F°/hour. An unplanned shutdown might stress the fish within the discharge canal, but these populations are not significant in size relative to populations in the river.

Fish may be attracted to heated discharges and resident there for several months.⁶² Premature spawning can be speculated to have many repercussions, ranging from loss of progeny due to lack of proper food to species changes brought about by the dominant large warm-water fry.

Even though the staff's thermal analysis indicates that, for operation of the once-through cooling system, the 4 F° surface isotherm would extend across the river under certain conditions (Sect. V.C.1), sufficient information is not available to quantify the probability of altering the behavior and spawning distribution of anadromous species due to thermal discharges.

REFERENCES FOR THE EXCERPT

56. Calhoun, A. J., C. A. Woodhull, and W. C. Johnson, "Striped Bass Reproduction in the Sacramento River System in 1948," *Calif. Fish and Game* 36(2): 135-145 (1950).
57. T. C. Farley, "Striped Bass, *Morone saxatilis*, Spawning in the Sacramento-San Joaquin River System during 1963 and 1964,"

pp. 28-43 in *Ecological Studies of the Sacramento-San Joaquin Delta*, J. L. Turner and D. W. Kelly, eds., Calif. Fish and Game Fisheries Bulletin No. 136, 1966.

60. Regier, H. A., "Ecological Factors Affecting Amounts of Protein Harvested from Aquatic Ecosystems," Chap. 16 in *Biological Efficiency of Protein Production*, J. G. W. Jones, ed., Cambridge University Press, 1973.
62. Raytheon Company, "Indian Point Ecological Survey: Final Report, June 1969-October 1971," for Consolidated Edison of New York, Inc.

5.6.1.2 Texas Instruments. The following conclusions are quoted from a recent Texas Instruments report.¹

The thermal plume produced by operation of the Indian Point facility is restricted to the upper portion of the water column in the river and is well within the temperature, width, and cross-section limits required at the power-generation level (up to 1075 MWe for Units 1 and 2) during field surveys conducted during 1974.

Abundance of fishes, especially those most often impinged at the Indian Point intakes, is more strongly associated with salinity distribution in the vicinity of the plant than with a particular thermal regime.

Thermal discharges from Indian Point have no detectable effect on the benthic communities in the region. Species composition and abundance are governed by seasonal and annual variations in the temperature and salinity regimes and by differences in the microhabitats in the river.

White perch (*Morone americana*) and striped bass (*Morone saxatilis*) prefer temperatures above those to which they are acclimated; temperatures avoided by these fishes are several degrees above those preferred; critical temperatures are above those avoided.

Atlantic tomcod (*Microgadus tomcod*) avoid temperatures expected in the thermal plume of Units 2 and 3 combined.

Thermal tolerance limits and critical temperatures for striped bass and white perch are above the thermal plume temperatures expected to occur at Indian Point.

Effects of temperature decreases (such as could be produced by plant shutdown) depend on the magnitude of the decrease, the rate of change, and the final temperature. Rapid

decreases to near-freezing from 15° - 18°C (59 - 64°F) can cause mortality among white perch and striped bass. However, maximum plume temperatures are only about 10°C (18°F) above ambient winter temperatures so mortality from cold shock is unlikely.

Temperatures in the thermal plume when river temperatures are highest (near 26°C or 70°F) do not exceed those which elicit avoidance behavior from white perch and striped bass.

Due to highly variable size and distribution of the thermal plume from Indian Point and its restriction to the surface of the river, it is unlikely that any fishes become "resident" in the plume or that the plume blocks their movements.

Based on the physical, chemical, and biological data relating to thermal effluents from the Indian Point facilities, there is little detectable impact on the ecology of the Hudson River in the vicinity of Indian Point.

5.6.1.3 New York University. The following conclusions relating to striped bass are quoted from a recent NYU report.²

Fifteen-day and one month old striped bass larvae displayed no reductions in survival following one-hour exposures to Indian Point Unit 2 discharge water with total residual chlorine concentrations of 0.10 mg/l and 0.15 mg/l, respectively. Striped bass juveniles survived one-hour drifts through the Indian Point discharge plume without lethal effects. The results of two-hour static bioassays on naturally declining chlorine residuals indicate that initial chlorine concentrations < 0.5 mg/l would generally not be toxic to juvenile striped bass. Striped bass juveniles actively avoided chlorinated Indian Point discharge water diluted to 3.5°C ΔT and 0.05 mg/l residual chlorine. These studies indicate that larval and juvenile striped bass entrained in the Indian Point discharge plume will experience no lethal effects resulting from temperature and chlorine exposures.

Studies comparable to the TI and NYU studies, both done at Indian Point, have apparently not been done at either Bowline or Roseton.

5.6.2 Dissolved oxygen

From IP3 FES, pp. V-110 and V-111.

Dissolved oxygen (DO) in the Hudson River is found to range from low summer values of 3 ppm to high winter values of 11 ppm,⁶² although there has been considerable discussion

concerning the accuracy of these data (FES, IP-2, p. II-19). Texas Instruments⁶³ reports that for 1972 the mean monthly DO levels in the Hudson River varied from 5.0 to 13.0 ppm. The NYS Department of Environmental Conservation maintains an automatic sampling station at Verplanck and has recorded in the summer months some values of DO less than 4.5 ppm. Values of less than 4.0 ppm were recorded at Lovett in 1970.⁶⁴

The source of reduction in DO that is of...staff concern... is the effect of the thermal discharge in the vicinity of Indian Point, where biota can be exposed to higher temperatures at reduced DO.... DO concentrations may occasionally be lower in the vicinity of Indian Point than if there were no thermal discharge from the Plant. At certain times of the year, when dissolved oxygen levels are low as a result of natural occurrences, such further reductions resulting from Plant operations could be harmful to certain components of the aquatic community. The applicant's modeling of DO levels in the vicinity of Indian Point has included physical-chemical factors but not biotic factors, such as increased metabolic oxygen demand of aquatic organisms and increased photosynthesis of phytoplankton at elevated temperatures.

The staff concludes that during extreme conditions of low freshwater flow, high river temperatures, and high densities of plankton, the discharged thermal waste from Units Nos. 1, 2, and 3 with once-through cooling together with discharges from Lovett and Bowline may reduce the dissolved-oxygen concentrations in the plume and in the vicinity of Indian Point to levels detrimental to aquatic life.⁶⁶ Mortality, reduced growth rates of larval and juvenile fish, and reduced production of phytoplankton and zooplankton may result.

REFERENCES FOR THE EXCERPT

62. Raytheon Company, "Indian Point Ecological Survey: Final Report, June 1969-October 1971," for Consolidated Edison of New York, Inc.
63. Texas Instruments, Inc., "Hudson River Ecological Study, First Annual Report," prepared for Consolidated Edison Company of New York, April 1973.
64. Quirk, Lawler, and Matusky, Engineers, "Environmental Effects of Bowline Generating Station on the Hudson River," vols. I-IV, QJ&M Project No. 169-1, March 1971.
66. Redirect-Rebuttal Testimony of C. P. Goodyear, "Dissolved Oxygen Concentrations in the Hudson as a Result of IP 1 and 2," Indian Point Unit No. 2 ASLB Hearings, Docket No. 50-247, February 22, 1973.

5.6.3 Chlorine

From IP3 FES, pp. V-113-V-115.

During chlorination, mortalities of organisms that pass through the condensers being chlorinated are expected to approach 100% for most species.

Although the New York State Department of Environmental Conservation and the Environmental Protection Agency¹⁴⁸ have established 0.5 ppm as the maximum concentration for chlorine discharges, there is evidence⁶⁷ to indicate that total residual chlorine concentrations as low as 0.1 ppm may have adverse effects.¹³⁹ Because of the sensitivity of different species at different life stages to chlorine concentrations below 0.5 ppm, the staff is concerned that the organisms in the thermal plume will be exposed to concentration levels of residual chlorine, chloramines, and chlorinated organics, which could result in deleterious effects.

The probability of causing serious impacts to the aquatic community would be lessened by chlorination schedules that coincide with peak tidal flows during daylight hours. This procedure would reduce the exposure of the planktonic crustaceans and larval fish that tend to concentrate near the bottom during daylight hours, because most of the toxic chlorine compounds will be in the thermal plume, which will be spread out on the surface as long as the thermal stratification factor is greater than 0.1.... However, even with these precautions, there is a higher potential for detrimental consequences of chlorine releases from Indian Point[, Bowline, and Roseton] than has previously been experienced.... Because neither the concentration nor the duration of exposure can be established with certainty, the level of impact which may be caused by releases of discharged chlorine...cannot be estimated with any certainty.

Overall, the chemical releases will be limited to protect the aquatic biota...in compliance with the Environmental Protection Agency's effluent guidelines and standards⁶⁹ through the...402 NPDES discharge permit for each Plant.¹⁴⁸

REFERENCES FOR THE EXCERPT

67. Becker, C. D., and T. O. Thatcher, "Toxicity of Power Plant Chemicals to Aquatic Life," Report WASH-1249, June 1973.
69. "Effluent Guidelines and Standards," *Federal Register* 39: 36186, October 8, 1974.

139. Brungs, W. A., "Effects of Residual Chlorine on Aquatic Life," *J. Water Pollut. Control Fed.* 45(10): 2180-2193 (1973).
148. U.S. Environmental Protection Agency, Region II, New York, New York 10007, Public Notice No. NPDES 74-1111, June 28, 1974, draft NPDES permit for Indian Point Generating Station Units 1 and 2.

See Sect. 5.6.1.3 for recent results from an NYU study of the effects of temperature and chlorine on entrained Hudson River organisms.

In the opinion of ORNL, the direct and indirect effects of discharges on the various life stages of young-of-the-year striped bass are expected to be minor in comparison with those from entrainment and impingement. The model results presented in Sect. 5.8 do not reflect any effects from discharges.

REFERENCES FOR SECTION 5.6

1. Texas Instruments, Inc., *Hudson River Ecological Study in the Area of Indian Point. Thermal Effects Report*, prepared for Consolidated Edison Company of New York, Inc., September 1976.
2. New York University Medical Center, Institute of Environmental Medicine, *The Effects of Temperature and Chlorine on Entrained Hudson River Organisms, Progress Report for 1975*, prepared for Consolidated Edison Company of New York, Inc., September 1976.

5.7 Compensation

The objectives of this section are (1) to define the concept of compensation, (2) to summarize the ORNL position on compensation as presented in the Indian Point Unit 3 FES, (3) to review the Texas Instruments evidence for compensation in the Hudson River striped bass population, (4) to present the highlights of an ORNL critique and sensitivity analysis of the compensation function used in the Lawler, Matusky, and Skelly Hudson River striped bass models, and (5) to present excerpts from two recent papers dealing with compensation in the context of assessing the population-level effects of power plant exploitation.

5.7.1 Concept of compensation

From IP3 FES, pp. V-127 and V-128.

Population regulatory mechanisms may, in general, be classified as density-independent or density-dependent and may act on various life stages of the populations involved. For a specified life stage, if mortality is controlled by density-independent factors, the population mortality rate (or the probability of an individual's dying) is independent of the population density of such organisms in the area under consideration. On the other hand, if mortality is controlled in a density-dependent manner, the mortality rate is correlated with, and is a function of, the population density. Traditionally, the term "density-dependent," when applied to population-regulation mechanisms, implies a positive relationship between density and mortality rates (high density implying increased mortality rates), with the result that a negative feedback exists which tends to stabilize population size. The concept of density-dependent mortality can, on the other hand, be extended to situations where an inverse relationship exists between population size and mortality rates. In such a situation, survival probability is increased with larger population size, and mortality rates are decreased. This inverse density-dependent mechanism would apply, for example, to the situation where mortality rates were predominantly a result of predation if a limited number of predators were involved and if they were satiated part of the time. Viewed in this manner, density-independent regulation can be considered a boundary condition that lies at the transition between inverse density-dependent relationships and (direct) density-dependent relationships. Inverse density-dependent regulatory mechanisms apply positive feedback and imply the existence of at least potential density-dependent regulation of some other life stage of the population, as well as the likelihood of population fluctuations.

5.7.2 Summary on compensation from the Indian Point Unit 3 FES

From IP3 FES, pp. V-143 and V-144.

From the staff's point of view, the concept of natural compensation, as opposed to compensation by the fishery, and the fact that natural compensation is occurring and will continue to occur to some degree, are not the issues in controversy. Rather, the primary issue, provided the applicant has not and will not be able to quantify the degree of natural compensation, is to what extent should the parties rely on compensatory decreases in natural mortality to offset the increased mortality due to the power plants. The staff's position is that to rely on natural compensation to any major extent is not environmentally sound. Thus, in reaching its conclusions in this Final Environmental Statement for Indian Point Unit No. 3, the staff has assumed that natural compensation of early life stages and older age classes is not likely to be of major importance in offsetting the increased mortality due to the power plants. However, the staff has included a compensation function in its young-of-the-year model^[1] to determine the effect of changes in the compensation parameters on the model results used to assess the potential impact of plant operation on the striped bass young-of-the-year population.

Given that (1) fishing mortality appears to be a more important source of mortality than natural causes for adult striped bass once they enter the fishery, (2) the sport catch substantially exceeds the commercial catch, and (3) the staff believes the sport fishing effort in particular is likely to be dependent on the size of the striped bass population, the staff has assumed that the combined fishery will respond in a compensatory manner, with or without new fishing regulations, to partially offset the increased mortality due to the power plants. On the basis of this assumption, the staff included a density-dependent, fishing-mortality function in its life-cycle model.^[2]

5.7.3 Texas Instruments evidence for compensation in the Hudson River striped bass population

Texas Instruments has presented (1) evidence of compensatory changes in abundance over five-year intervals in striped bass commercial fishery data (catch per unit effort, CPUE) from the Hudson River and (2) evidence of compensatory growth differences of young-of-the-year striped bass in the Hudson River.

5.7.3.1 Texas Instruments stock-recruitment analysis

(From ref. 3, pp. VIII-2 to VIII-7).

Between 1955 and 1972, there was a highly significant negative linear relationship between CPUE and CPUE 5 years later ($r = -0.811$, $df = 11$, $p = 0.00078$). Thus, the striped bass population appears to have changed in a density-dependent manner over the abundance range represented by the Ricker curve's right limb (Figure [5.7.1]). Although density-independent factors may have contributed to population shifts since 1955, the magnitude of their contribution is unknown. In view of the strong stock-recruitment relationship, it seems likely that some truly density-dependent population changes occurred. These changes would indicate that the Hudson River striped bass population probably has the capacity to compensate to some extent for increased mortality such as that imposed by power plants. This compensation would seem to occur over a wide range of stock densities (roughly two-thirds of the entire observed range).

The probable biological basis for the strong relationship using the 5-year lag between stock and recruitment is that the majority of the Hudson's female striped bass mature at age 5 and these 5-year-old females contribute the predominant fraction of the population's total natality. Assuming that recruited female striped bass suffer an annual total mortality of 50%, 5-year-old females account for 41% of the total natality.... Given such a stock-recruitment function, compensatory mechanisms must be operant at some time prior to maturation.

5.7.3.2 Texas Instruments density-dependent growth analysis

(From ref. 3, pp. VIII-8 to VIII-11).

The uncorrected correlation coefficient relating young-of-the-year density and growth for striped bass was $r = -0.719$ ($df = 6$, 2-tail $p < 0.05$), indicating a significant negative linear correlation of growth with density (Figure [5.7.2]). A stronger relationship between growth and density in young-of-the-year striped bass emerged when fluctuations related to water temperature were removed by partial correlation. The partial correlation between growth and density with temperature effects held constant was highly significant using either 1-tailed or the more conservative 2-tailed tests ($r = 0.866$, $df = 5$, 2-tail $p = 0.0117$, 1-tail $p = 0.0058$). Holding temperature effects constant increased the correlation between growth and density because temperature was negatively (but not significantly) related to both CUPA [catch per unit area] ($r = -0.387$, $df = 6$, $p = 0.344$) and growth ($r = -0.174$, $df = 6$, $p = 0.680$).

Fig. 5.7.1. Striped bass abundance vs abundance five years later during 1955-1972. Source: Texas Instruments, Inc., *First Annual Report for the Multiplant Impact Study of the Hudson River Estuary*, prepared for Consolidated Edison Company of New York, Inc., vols. I and II, July 1975, Fig. VIII-3.

Fig. 5.7.2. Young-of-the-year striped bass growth vs abundance.
Source: Texas Instruments, Inc., *First Annual Report for the Multiplant Impact Study of the Hudson River Estuary*, prepared for Consolidated Edison Company of New York, Inc., vols. I and II, July 1975, Fig. VIII-4.

Some of the increase in the growth-abundance correlation may have been obtained by removing effects of the relationship between temperature and time of spawning. However, temperature and growth were not strongly related in this study.

Both simple and partial correlations lead to the conclusion that growth and abundance of young-of-the-year striped bass in the Indian Point area were negatively related; i.e., their growth was density-dependent in the years studied. Although the relationship observed at Indian Point in all probability holds in the striped bass population throughout the Hudson, year-to-year variations in fish distribution make extrapolations from Indian Point to the Hudson as a whole unreliable in a particular year. It is also possible that the apparent growth-abundance relationship was produced by size-selective density-dependent migration affecting the Indian Point region. If during years of low abundance relatively large young-of-the-year striped bass tended to predominate at Indian Point because of a net positive size balance of immigration and emigration during July and August and if during years of high abundance migration's net effect on young-of-the-year size was negative, locally observed size changes would not truly represent growth within the region. However, there is no evidence of such a migratory pattern, and its occurrence seems rather improbable.

5.7.3.3 ORNL preliminary review of the TI stock-recruitment analysis.

In reviewing the TI stock-recruitment analysis, ORNL examined the relationship using a four-year lag, a six-year lag, and a seven-year lag, in addition to the five-year lag report by TI. ORNL also examined this relationship using the same three lag intervals after adding the data points for 1973, 1974, and 1975. Because the striped bass commercial fishery in the Hudson River is closed due to the PCB problem, no additional data points past 1975 will be available until some unknown time in the future. The ORNL analyses are summarized in Table 5.7.1.

To the extent that the commercial CPUE index is a measure of stock size, a negative correlation obtained with a lag of N years implies a periodicity of $2N$ years in the index itself (and hence in the stock size) (see ref. 4, pp. 568-572 and 583-586). A spectral analysis of the CPUE index between 1955 and 1975 indicates a dominant periodicity of approximately nine years (Figs. 5.7.3-5.7.6). However, if this periodicity results from a simple causal relationship between stock size and the success of recruitment, it implies that striped bass make their median contribution to reproduction at approximately age 4 to 5. This age for median contribution to reproduction seems highly unlikely for the Hudson River striped bass stock. Even if the five-year-olds make as large a contribution to reproduction as suggested by the TI analysis (ref. 3, Table VIII-1), the age of median contribution is much closer to six years than to four or five years. Additional analyses may, in fact, support an age of median contribution to reproduction closer to seven years than

Table 5.7.1. Summary of ORNL analyses of the striped bass commercial fishery data from the Hudson River

Lag (years)	1955 - 1972		1955 - 1975	
	r^a	p^b	r^a	p^b
4	-0.68	0.007	-0.21	0.58
5	-0.81	0.0008	-0.62	0.01
6	-0.24	0.46	-0.22	0.57
7	+0.22	0.50	+0.06	0.93

r^a is the standard linear correlation coefficient.

p^b is the probability of a type I error, i.e., the probability of rejecting the null hypothesis that the true correlation, ρ , is zero when, in fact, the null hypothesis is true. The alternative hypothesis is that ρ is not zero, i.e., a two-tailed test.

Fig. 5.7.3. Catch per unit effort, 1955-1975.

Fig. 5.7.4. Serial correlation coefficient vs time lag.

Fig. 5.7.5. Fourier spectrum.

Fig. 5.7.6. Maximum entropy spectrum.

to six years. As shown in Table 5.7.1, the only significant correlations are with four-year and especially five-year lags. Correlations for all lags are weakened by inclusion of data points for 1973, 1974, and 1975.

A quotation from Ricker (ref. 5, pp. 234-235) seems appropriate here.

In general, tentative relationships deduced from an exploratory study involving several to many factors must always be confirmed by additional information. This additional information can be more observations of the kind already used, as they accumulate in the future. With fish populations, ten years or so is usually required to obtain confirmation in this manner. To get a quicker answer, experiments or observations can sometimes be made to determine the exact causal nature of any relationship suggested by the correlations — which is very desirable anyway, whenever possible. An observed correlation gains vastly in acceptability if the implied biological process can be demonstrated to occur, even if only qualitatively.... The effect which initially seems most "significant" may decrease in apparent relative importance or even subside into insignificance, while some originally "non-significant" effect may become demonstrably important, as future years' data are added to a correlation series.

5.7.3.4 ORNL preliminary review of the TI density-dependent-growth analysis. In response to questions submitted by ORNL, TI submitted the original data used to calculate the relationship between growth from July to August and abundance (measured as catch per unit area, CPUA, in July) in young-of-the-year striped bass and white perch. These data, however, refer not to Fig. 5.7.2 but to Fig. 5.7.7, from a more recent report.⁶ The growth and CPUA data for the years 1966-1974 have apparently been recalculated; many of the values are substantially different in the later report. Using the recalculated data, the correlation between growth and CPUA is significant at the 1% level ($r = -0.85$, seven degrees of freedom) using either a one-tailed or a two-tailed test (Fig. 5.7.7). In the 1977 report the correlation is not adjusted to eliminate the effect of temperature on growth.⁶

TI has interpreted these data as indicating that intraspecific competition, resulting in reduced growth rates at high population densities and increased growth rates at low densities, is occurring in young-of-the-year striped bass in the Hudson River. ORNL believes, however, that there is still considerable doubt about whether the observed correlation is in fact a result of intraspecific competition. Even if there is a causal relationship between density and growth in young-of-the-year striped bass, its significance as a compensatory mechanism is open to question.

It is well established that, because of intraspecific competition for food and space, growth rates in post-first-year fish are frequently inversely related to density. In fact, it has been argued that

Fig. 5.7.7. Relationship of juvenile striped bass density in Indian Point area to changes in mean lengths (growth) from July to August 1965-1975. Modified from J. T. McFadden, ed., *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*, submitted to Consolidated Edison Company of New York, Inc., 1977.

density-dependent growth is the most important and easily observable compensatory mechanism in fish that have survived their first year of life.⁷ Some information exists pertaining to functional relationships between density and growth in young-of-the-year fish. In addition to the results reported by TI, significant negative correlations between growth and density have been reported for two other anadromous fish populations in the northeastern United States: American shad in the Connecticut River⁸ and white perch in the Patuxent River.⁹ The importance of density-dependent growth as a compensatory mechanism in young of the year has been demonstrated in trout¹⁰ and sockeye salmon.¹¹

Because the existence of intraspecific competition, resulting in density-dependent growth, has been convincingly documented in a variety of fish populations, it is clearly possible that this compensatory mechanism is operating in Hudson River striped bass. However, an examination of TI's data on white perch growth and abundance casts some doubt on this interpretation. If young striped bass compete with each other for food and/or space, they should also be competing to some degree with other fish that occupy the same space and feed on the same food. In particular, competition should be observable between striped bass and white perch. Larvae of these two species are nearly indistinguishable (they are congeneric) and occupy the same reaches of the Hudson River; juveniles of both species are found in the same shoal and beach areas and have extremely similar diets.¹² Therefore, if competition is occurring in striped bass, it should also be occurring in white perch and between striped bass and white perch. The data supplied by TI show no evidence of such competition. There is no correlation between growth and abundance of young-of-the-year white perch for the years 1966-1974 ($r = 0.03$, NS, 6 df), no correlation between striped bass growth and total CPUA of striped bass and white perch combined ($r = -0.02$, NS, 6 df), and only a weak correlation between striped bass CPUA and white perch CPUA ($r = -0.30$, NS, 6 df). There are three possible explanations for these low correlations: (1) The sampling program employed by TI may be inadequate for measuring white perch growth and density. Density-dependent relationships within white perch and between white perch and striped bass may exist but may be obscured by high sampling error. (2) The two species may not really compete. Although they feed on the same organisms and occupy the same river, they could exploit different microhabitats within the river. (3) Intraspecific competition may not be occurring in striped bass, and the apparent negative correlation between growth and density may be simply a statistical artifact. Both density and growth may be correlated, in opposite ways, with some unmeasured environmental variable. It does not appear at this time that there is enough evidence to eliminate any of these possibilities.

Even if density-dependent growth exists in young-of-the-year striped bass, its importance as a compensatory mechanism has not been established. Presumably, if power plant cropping reduced the abundance of larval and juvenile fish, those that were not cropped would grow faster and attain a larger size, and because of this they would have a greater chance of surviving to adulthood. However, there is reason to doubt whether

density-dependent growth, if it is operating, has a significant effect on the size attained by striped bass by the end of year zero. The reason for this is the phenomenon known as growth compensation, which is the tendency for small fish to grow faster than large fish of the same age. The supplementary data supplied by TI clearly demonstrate that growth compensation occurs in Hudson River striped bass. The correlation between the mean length of juveniles in July and their subsequent growth is negative and statistically significant ($r = -0.78$, $p < 0.05$, 6 df). When the relationship between striped bass CPUA and mean length of juveniles in August was examined, the correlation, although negative, was not significant ($r = -0.51$, $p > 0.20$, 6 df). The variance in mean length of striped bass in August was less than half that in July, although the difference in variance was not statistically significant ($F_{8,8} = 2.34$, $p > 0.10$).

Thus, because of growth compensation, there appears to be a strong tendency for juvenile striped bass to attain the same length at the end of the summer regardless of their abundance or their length earlier in the year. This does not, however, imply that size is completely independent of density. If the effects of July length on growth are eliminated by means of partial correlation, the correlation between growth and CPUA is still significant ($r = -0.86$, $p < 0.02$, 5 df). Density may well influence size, but the effect is clearly a small one. If the regression of August length on CPUA in July is examined (August length = $64.04 - 0.07 \text{ CPUA}$), it can be demonstrated that halving the density of striped bass from 20 to 10 fish per square meter in July would result in only a 1% increase in mean length in August.

The fact that population density has only a small effect on the size attained by young-of-the-year bass does not imply that density-dependent growth is insignificant as a compensatory mechanism. Depending on the relationship between size and mortality in these fish, its effects could be either substantial or negligible. If a 1% increase in the length of a fish increased its daily probability of survival by 1%, its probability of surviving through the next month would be increased by a factor of 1.34 (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. Information about the effects of size on mortality in young-of-the-year striped bass is therefore crucial to a scientific assessment of the importance of density-dependent growth as a compensatory mechanism in this fish.

In conclusion, the data supplied by TI are consistent with the hypothesis that growth in young-of-the-year striped bass is a function of density, but they are by no means conclusive. Although a statistical correlation has been found, it is still necessary to establish a causative mechanism and to explain why this mechanism is operating in striped bass but is not operating, or at least is not observable, in white perch. Even if a functional relationship between growth and density does exist, the importance of density-dependent growth as a compensatory mechanism cannot be assessed in the absence of knowledge about the relationship between size and mortality in young-of-the-year striped bass.

In summary, the TI presentation of evidence of compensation in the Hudson River striped bass population is one of the more interesting results of the extensive research and monitoring programs that have been supported by the various utilities on the Hudson River. While there are uncertainties and problems associated with each analysis, the two analyses do suggest that some density-dependent population changes may have occurred during the period 1955 through 1973. In ORNL's judgment, a reasonable position, as required by ALAB-188¹³ and discussed in the Partial Initial Decision for the Summit Power Station,¹⁴ is that the Hudson River striped bass population probably has the capacity to compensate to some extent for increased mortality such as that imposed by power plants. However, the TI analyses do not remove ORNL's concern for the long-term consequences of a protracted increase in density-independent mortality, such as the cropping imposed by power plants, since the range of cropping rates which could be offset by compensatory responses and the degree of offset are not known.

5.7.4 Lawler, Matusky, and Skelly compensation function

Oak Ridge National Laboratory has recently completed a critique and sensitivity analysis of the compensation function used in the Lawler, Matusky, and Skelly (LMS) Hudson River striped bass models.¹⁵ The highlights of this report are summarized below.

INTRODUCTION

The primary issue in controversy with respect to estimating the effects of entrainment and impingement on the Hudson River striped bass population is the extent to which regulatory agencies, utilities, and society should rely on compensatory decreases in natural mortality to offset the increased mortality due to the power plants. This issue is of particular importance in terms of how compensation is included in striped bass simulation models, because the handling of compensation appears to account for the major part of the difference among estimates of percent reduction in the striped bass population.

The objectives of this report are (1) to present the description and justification for the compensation function developed and used by Lawler, Matusky & Skelly Engineers (LMS) (under contract to Consolidated Edison Company of New York), and (2) to present a sensitivity analysis and critique of the LMS compensation function.

DISCUSSION

Conceptual Basis for the LMS Compensation Function

We feel that the LMS mathematical formulation, as described under *LMS formulation of compensation*, is not conceptually sound. As

implemented in the three LMS striped bass models,^{1,2,3} the assumption is made that without the new power plants (Indian Point Units 2 and 3, Bowline, and Roseton), "the system is in relative balance or at relative equilibrium, and there is little active compensation." For young-of-the-year life stages of striped bass, it is difficult to visualize a source of mortality that (1) is a minimum near zero density, (2) increases (although at a decreasing rate) at low densities to reach a plateau over a range of intermediate densities (0.42 to 0.68 in [Fig. 5.7.8] for the Juvenile 1 life stage), and then (3) increases again (but now at an increasing rate) at a high density. For example, it is not reasonable to hypothesize a curve with this entire shape due solely to crowding or less food per unit number of fish as density increases.

In particular, there is not a sound biological basis for the left limb of the [solid curve] in [Fig. 5.7.8] for fish species such as striped bass. Much of the theory of compensation in animal populations is based on experience with [higher vertebrates and in terrestrial] populations. In these populations there may be sound biological bases for hypothesizing the left half of the [solid curve] in [Fig. 5.7.8], which show a decreasing mortality coefficient and an increasing probability of survival as density decreases to very low values. The biological bases for this type of curve involve refugia, territoriality, food preferences of predators on target species (e.g., young-of-the-year striped bass as the target species), and other behavioral phenomena that tend to be more highly developed in [higher vertebrate and in terrestrial species (e.g., insects)] than in nonterritorial fish species such as the striped bass. Based on model results LMS has presented to date, it is not clear which half of the [solid curve] in [Fig. 5.7.8] is the more important in offsetting the power plant impact. However, because the density in each river segment initially starts at zero and finally drops back down to zero, the left limbs of these curves are certainly utilized.

In our opinion, a mathematical formulation for compensation for striped bass with a more sound biological basis is one that has a plateau extending from zero to some critical density. Above this critical density the density-dependent parameter increases (e.g., mortality rate coefficient and duration) or decreases (e.g., growth rate coefficient and probability of survival) with further increases in density due to resource limitations or selective predation.⁹ The compensation functions used in both [the ORNL] young-of-the-year model¹⁰ and [the ORNL] life cycle model¹¹ have this property.

...This type of function is analogous to the plateau and right limb of the compensation function used by LMS ([Fig. 5.7.8]). Given this formulation, the major issue (i.e., the extent to which regulatory agencies, utilities, and society should rely on compensatory changes in mortality to offset the increased mortality due to the power

Fig. 5.7.8. Exponential mortality coefficient vs concentration of juvenile is showing the effect on the curve of disabling the left or right limb of the compensation function. Equivalent symbols used elsewhere in this report: $Y_S = N_S$; $K_X = K_E$; $K_{X0} = K_0$. Modified from Fig. 9 of J. P. Lawler, "Effect of entrainment and impingement at Indian Point on the population of the Hudson River striped bass," testimony before the Atomic Safety and Licensing Board, Indian Point Unit 2, USAEC Docket No. 50-247, October 30, 1972.

plants) reduces to choosing: (a) critical densities; (b) steepness of the right limbs of curves, and (c) where to assume the population would exist on the curve without the additional power plant mortality.

We are also concerned about the conceptual relationship between the three parameters in the LMS compensation function and actual biological phenomena.

YS

The parameter YS [= N_s in Fig. 5.7.8] for a given life stage is defined as the equilibrium population level in the Hudson River. In our opinion the entire concept of an equilibrium population level for any of the young-of-the-year life stages is inappropriate. Within a year, the young-of-the-year population consists of a series of linked transients, with one life stage overlapping with both the preceding and succeeding life stages. To speak of an equilibrium population level for each life stage in such a system is meaningless. In dealing with comparisons among years, only the concepts of an average maximum standing crop and an average transient curve for a given life stage have operational meaning. In summary, it is our opinion that the parameter YS has no operational meaning for the transient dynamics of the young-of-the-year life stages, and it cannot be based directly or indirectly on observed standing-crop or density data.

KX

The parameter KX [= K_e in Fig. 5.7.8] is defined by LMS as the equilibrium first order mortality rate coefficient.^{1,2} LMS calculates this parameters as $-\ln(PS)/DTE$ for each life stage, where DTE is the time required to pass through a given life stage under equilibrium conditions and PS is the probability of survival through that life stage under equilibrium conditions. However, all that can be estimated from field and/or laboratory data are DTE', an average time required to pass through a given life stage, and PS', an average probability of survival through that life stage. DTE' and PS' could then be used to calculate an average first order mortality rate coefficient (KX') as $KX' = -\ln(PS')/DTE'$, assuming exponential mortality. Only by chance would DTE' = DTE, PS' = PS, and/or KX' = KX, because the average values will reflect biological phenomena occurring over the full range of population densities achieved in the natural system, and not just at an "equilibrium" standing crop or density (however defined). Thus, the parameters necessary to calculate KX cannot be directly estimated from observable data.

KX0

The parameter KX0 [= K_0 in Fig. 5.7.8] is defined as the minimum mortality rate coefficient, which is approached at population levels near zero. We already have implicitly criticized the

biological basis for this parameter in the previous discussion about the left limb of the [solid curve] in [Fig. 5.7.4] for fish species such as striped bass.... Another point to be made about KX0 is that the values selected by LMS commonly correspond to unrealistic probabilities of survival....

Sensitivity Analysis

Sensitivity analysis, involving systematic variation of parameters through a range of values, is a standard way of evaluating and even validating simulation models. On the basis of examining model output, one can answer such questions as: (a) what is the relative sensitivity of the model to changes in certain parameters, and (b) is the model output reasonable or even plausible for a given parameter combination?

With respect to the three parameters in the LMS compensation function and the output variable of primary interest (viz., percent reduction in the striped bass population due to power plant operation), and given the range of parameter values used in this study, the model is least sensitive to changes in KX0, the minimum mortality rate coefficient. For example, estimates of percent reduction in number of adults at year 40 range from 15 to 49% for YS, 3 to 44% for KX, and 8 to 85% for KX0. Variations of this magnitude obviously must be considered in reaching a reasoned decision on the potential impact of the Hudson River power plants on the striped bass population. This concern is accentuated by the lack of a sound biological basis for the parameters YS, KX, and KX0.

A more fundamental type of sensitivity analysis involves comparing alternative forms for a function in a simulation model, where each form of the function reflects a somewhat different set of assumptions and understanding about how the real-world system may operate. We have been critical in this report of the conceptual basis for the left limb of the LMS compensation function. [In addition, Fig. 5.7.9 illustrates that for all values of KX0/KX] disabling the left limb results in appreciably higher estimates of percent reduction. Thus, again, results of this type must be considered in reaching a reasoned decision on the potential impact of the Hudson River power plants on the striped bass population.

Fig. 5.7.9. Dependence of percent reduction in number of yearlings at year 40 on the value of KX_0/KX . Neither limb of the compensation function disabled (●—●), left limb disabled (Δ—Δ), and right limb disabled (○—○).

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9. W. W. Murdoch and A. Oaten, "Predation and population stability." pp. 1-131 IN A. MacFadyen (ed.) *Advances in Ecological Research*, vol. 9, Academic Press, New York (1975).
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The model results presented in Sect. 5.8 include model runs with the original LMS compensation function as well as runs with the left limb of this function disabled.

5.7.5 Excerpts from two recent papers

McFadden¹⁶ and Goodyear,¹⁷ among others participating in the Conference on Assessing the Effects of Power-Plant-Induced Mortality on Fish Populations, held in Gatlinburg, Tennessee, May 2-6, 1977, have recently addressed the topic of compensation in the context of assessing the population-level effects of power plant exploitation. Excerpts from these two papers follow.

AN ARGUMENT SUPPORTING THE REALITY OF COMPENSATION IN FISH
POPULATIONS AND A PLEA TO LET THEM EXERCISE IT

J. T. McFadden

INTRODUCTION

The concept of compensation is very important in assessing the impact of power plant operation on fish populations because compensation represents the capacity of a fish population to offset, in whole or in part, reductions in numbers caused by entrainment and impingement. Not everyone has rushed to embrace the concept, however. In fact, government regulatory agencies and their scientific staffs involved in power plant licensing proceedings have seemed reluctant to credit many fish populations with significant natural compensatory capacity and even more reluctant to make quantitative allowance for this capacity when evaluating power plant impact. An example, presented for its utility not as a criticism, is the original position of the U.S. Nuclear Regulatory Commission on Indian Point Unit 2 on the Hudson River in New York and later applied to the proposed Summit Power Station Units 1 and 2 in Delaware: "Examination of relevant information concerning striped bass populations has led the staff to conclude that density-dependent regulatory processes as described above are not operative in East Coast striped bass larval and juvenile populations, because the breeding stock is not sufficient to saturate the nursery areas to population levels at which such processes would be operative" (USAEC 1974, citing USAEC 1972). Some softening of this stand was reflected in the NRC staff's review of Indian Point Unit 3 (USNRC 1975) and its testimony for the Summit Power Station (Christensen et al. 1975) for which it was maintained that the fishery operates in a compensatory manner but that natural compensatory processes should not be relied on to a major extent to offset power plant impact in heavily fished populations.

By contrast, I have always maintained, as a general proposition, that some natural compensatory capacity must be recognized as a logical necessity; that general observation of natural populations, a wide range of specific scientific studies, and the prevailing concepts of the field of fishery management all support this view; and that the operation of compensation must be taken into account in order to make realistic decisions in management of fish populations, whatever the source of disturbance or impact. Most people seem to intuitively expect that killing some fish will reduce the size of the population — a proposition which seems logical enough but is not always true. Upon a little reflection, I would argue that it should be at least equally obvious that a sustained removal of fish from a population will eventually result in reduced natural death rate or increased reproduction by the remainder.

This paper presents an argument in favor of the reality of compensation in fish populations — it is not a balanced examination of pros and cons. The ideas, at first developed in the relative tranquility of an academic environment, have been shaped through a succession of regulatory agency hearings in which too much open-mindedness has seemed the short road to intellectual extinction. They are called "adversary" proceedings for good reason. Hence, while trying to be fair and logical, my main goal has been to make converts rather than compromises. Success has been limited, but I remain optimistic....

COMPENSATION IN FISH POPULATIONS

Both the historical development of the general concept of compensation and the formal argument presented above support the view that compensation is operative in fish populations. This section supports this view with three additional lines of evidence:

- The historical development of the concept is traced through its applications in fishery management, and the present-day consensus held by the world's leading fishery scientists is summarized.
- A selection of compensatory mechanisms that have been convincingly demonstrated to operate in fish populations is reviewed.
- A large number of cases, in which substantial levels of exploitation by sport or commercial fisheries have been sustained by fish populations without serious depletion, are cited....

Capacity of Fish Populations to Withstand Mortality

While it is clear that the concepts in fisheries science were developed through experience with stocks subjected to exploitation by man, nothing explicit has yet been stated here about the degree of resiliency possessed by these stocks. Remaining unanswered are such questions as how large an annual removal can be sustained, at what level of added mortality will the population be drastically reduced in numbers, at what level of added mortality will it be threatened with extinction, and what would constitute an intolerable or irreversible reduction of a fish population. As a foundation for responding to these questions from a basis of empirical evidence, the principles unfolded through the arguments and historical accounts previously presented are summarized as follows:

- An undisturbed or unexploited population (one at the maximum equilibrium level on the average) produces enough new individuals to just replace natural losses; there is no surplus production.
- A population, if it is to be held at maximum size, cannot be exposed to any additional mortality either from natural causes or from man's activities because, at maximum stock size, no surplus production is available to absorb an increment of mortality.
- At the opposite extreme, as a population approaches 0 size, surplus production approaches 0. In very small populations, the rate of surplus production per individual is very high; however, so few individuals are present that the overall rate of increase for the population is very low.
- Should exploitation or some other form of environmental impact occur, population size will be reduced. At levels of density lower than equilibrium, surplus production will be available to absorb the environmental impact while maintaining the population at the new but reduced level.
- Maximum surplus production occurs at some intermediate level of stock density.
- If an added mortality is large enough, population size will be reduced to a level at which the fish may become undesirably scarce, and the population may be vulnerable to accidental or even inevitable extinction and may be able to generate only a small surplus production for the benefit of man or as a cushion against further decline....

Experience with the world's major stocks has proven both that they have the capacity to withstand impressively high levels of exploitation and produce a substantial surplus at population levels well below their pre-exploitation abundance, and that they have the ability to rebound to higher levels of abundance after being heavily exploited if fishing intensity is reduced. This is entirely in keeping with the concepts of population dynamics, and there is important empirical proof of this recovery capacity. Fishing reduced the plaice stock in the southern North Sea to one-third or one-half its original abundance, but relaxation of fishing during wartime rapidly doubled its size (Cushing 1975, p. 135). The Pacific halibut population decreased by a factor of 7 during a 20-year period of fishing, then increased in size when protected by a closed season (Fukuda 1962). A North Sea herring stock was reduced to one-tenth its previous abundance during a 12-year period and subsequently began to increase as a result of reduced fishing pressure (Cushing 1975, p. 136). Sturgeon fishing in the Amur River basin was banned for 12 years

to restore overfished stocks; by the end of the ban, the proportion of sexually mature fish had increased sixfold and the average size and age of fish had increased as well — evidence of restoration of the stock (Krykhtin 1972). Similar examples are reported for the whitefish of Lake Wabamun (Miller 1949) and for lake trout of Lake Opeongo (Fry 1949). Thus, reductions in fish stocks caused by exploitation have commonly been proven to be reversible.

APPLICABILITY OF FISHERY EXPLOITATION PRINCIPLES TO POWER PLANT IMPACTS

Cushing (1975, p. 138-139) points out that "Many populations of wild animals are exploited but the commercial fish stocks are numerous.... No other wild populations have been so well documented for such long periods of time." This imposing body of accumulated experience with fish populations has provided the basis for the development of successful management principles in fishery science. However, are these principles and the experience from which they are derived, based as they are on fishery exploitation of the (usually) mature age groups of a stock, applicable to the situation in which some fraction of the earliest life stages (eggs, larvae, and juveniles) is cropped by entrainment and impingement? Can the contention that "The agent of mortality — predatory fish, commercial or sport fisherman, or power plant — is an indifferent matter from the standpoint of population response" be sustained? The questions are important ones. If answered affirmatively, any empirical evidence for compensation in a particular stock, in combination with one of the generally proven compensation models based upon the entire foundation of fishery-management science (e.g., Ricker or Beverton-Holt stock recruitment function), can be used to provide estimates of power plant impact. This taking into account of compensation would greatly increase the degree of realism associated with assessing the effects of power-plant-induced mortality on fish populations.

It turns out that the question whether it is different (possibly worse) to kill young fish than to kill older fish was answered more than 20 years ago by Ricker (1954).... Ricker goes on to say "... it is clear that any general prejudice against exploiting young fish is unsound." Ricker's analysis of the situation has not been challenged. Insofar as population response is concerned, no different principles are involved. Killing some fish during the egg, larval, and juvenile stages (which is what power plants do) is no worse than killing the parents that would have produced these young (which is what fisheries do). The entire foundation of fishery management experience and principles, therefore, can be applied with confidence to problems of power plant impact. It can be reasoned that fish populations can readily sustain "exploitation" by power plants at levels comparable to those experienced in

commercial and sport fisheries. In a well-managed fishery, an annual exploitation rate of 50% or more for some species might well be a goal eagerly sought by fishery managers and fishermen rather than a threat to be guarded against. Even for species with rather low compensatory capacity, an exploitation rate of approximately 30% and reduction of the stock to about 46% of its pre-exploitation abundance would be necessary to achieve the very conventional goal of maximum sustained yield (Ricker 1958, p. 268).

As has been pointed out, the workability of such management plans, based on current fishery concepts and models, has been directly proven by empirical data such as that summarized in Table 2. A 50% exploitation rate in a fishery, however, is not likely to be comparable to a 50% exploitation rate caused by a power plant. Once a particular year class of fish becomes vulnerable to a fishery, it is likely to be exploited during each remaining year of its life, although the rate may vary with age. For example, assuming recruitment to the fishery at age 4, a 50% exploitation rate could well mean that half the members of age class 4 are captured, half of the survivors of age class 4 are captured at age 5, and so on for older age classes.

Compared with this annually repeated fishery mortality, a 50% exploitation rate caused by a power plant, which would affect each year class only once during its lifetime (during the first year when the young are entrained or impinged), would represent a very much smaller mortality. What relative impacts, measured in terms of stock reductions, the two mortalities would be translated into depends on the characteristics of the fishery. Clearly, the power plant mortality, falling as it does on the very young, precedes the age of first reproduction. The fishery mortality, on the other hand, could begin several years after the fish first reproduce, and some part of the population's reproductive potential would then be protected from reduction. However, most fish reach a size desirable in sport or commercial fisheries by the age at which they make significant reproductive contributions. Therefore, the common case will be for a given exploitation rate caused by a fishery, and hence repeatedly imposed in successive years on each year class of fish, to translate into a greater impact than would the same exploitation rate caused by a power plant, and hence imposed only once on each year class.

In most real-world situations, power plant impact would be added to a pre-existing fishery exploitation rate rather than applied to an unexploited stock. Even in this case, however, the addition of an exploitation rate greater than 25% to a pre-existing fishery exploitation rate of 25% would not endanger the stock of many species.

ASSESSING THE IMPACT OF POWER PLANT MORTALITY ON THE COMPENSATORY RESERVE OF FISH POPULATIONS

C. P. Goodyear

INTRODUCTION

One of the critical problems in the assessment of the impact of power plants on populations of commercially or recreationally important fishes is our limited understanding of the mechanisms that control population change. It is comparatively easy to estimate the proportion of eggs, larvae, or juveniles which may be killed by power plant operation. Unfortunately, this information is not always sufficient to make sound management decisions related to siting or continued operation of individual power plants. Such decisions also require knowledge of the impact of the identified losses on the long-term health of the population and on the associated yield to fishermen.

The problem of predicting population responses to changes in mortality is not restricted to analysis of the impact of power plants but rather is a key problem in fishery research in general (Cushing 1968, Hunter 1976). The same mechanisms that will dictate the long-term consequences of power plant mortality are responsible for the relationship between spawning stock and recruitment. These mechanisms can be broadly categorized as compensatory and include such phenomena as cannibalism and density-dependent starvation, growth, predation, fecundity, etc. The operation of these types of mechanisms enables a population to be exploited by man without its dwindling to extinction.

The continued existence of fish populations undergoing exploitation is ample evidence for the operation of compensatory mechanisms within the life cycles of those populations. However, there is a limit to the degree that these mechanisms can offset the additional mortality caused by increasing exploitation, as evidenced by the catastrophic failure of some fisheries (e.g., Burd 1974).

The purpose of this paper is to present a technique for quantifying the degree to which compensatory phenomena are exerted in exploited populations and to examine the impact of power-plant-induced mortality on this measurement of compensation....

Any analysis of the effects of power-plant-caused mortality on a fish population must consider all of the other sources of mortality that are being imposed by man's activities. Each additional source of mortality will remove some of the compensatory reserve of the stock until ultimately it can sustain no more. When this point is surpassed the stock will dramatically decline and may never be able to recover.

From the standpoint of managing our fish resources we should seek to maintain sufficient compensatory reserves to allow the populations to sustain additional unpredicted mortality. For exploited populations, the mortality caused by power plant operations will, at a minimum, reduce this margin of safety and make the affected resource more vulnerable to destruction.

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5.7.6 Summary

In agreement with the McFadden and Goodyear excerpts in Sect. 5.7.5, ORNL readily endorses the concept of compensation and the likelihood that compensation (both natural and through the fishery) is occurring and will continue to occur in the Hudson River striped bass population. However, ORNL is also in agreement with the Goodyear excerpt and shares the concern that there is "a limit to the degree that these mechanisms can offset the additional mortality caused by increasing exploitation" and that "each additional source of mortality will remove some of the compensatory reserve of the stock until ultimately it can sustain no more." Thus, in the opinion of ORNL, the primary issue in controversy for regulatory agencies, utilities, and society in general is the amount of compensatory capacity which a priori should be assumed to exist in the population and, therefore, the extent to which the effects of increased mortality due to power plants will be offset.

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5.8 Model Estimates of Percent Reduction

5.8.1 Introduction

All model estimates of percent reduction presented in this report were obtained using the Lawler, Matusky, and Skelly (LMS) one-dimensional, tidal-averaged transport model for the Hudson River striped bass young-of-the-year population and the LMS completely mixed model. Collectively, these two models are referred to as the LMS 1-D model. Documentation of this model is available in refs. 1-3. This model alone was used in preference to using both this model and the ORNL young-of-the-year and life-cycle models^{4,5} because in ORNL's judgment, the most important issues in controversy (f factors and compensation) have been obfuscated by each party having its own set of models and then debating the relative merits of the models. While the LMS 1-D model could be improved in a number of ways, ORNL feels that the basic structure of the model is reasonable and that it provides an adequate tool for estimating both the short-term impact (i.e., percent reduction in yearlings after one year of plant operation) and the long-term impact (e.g., percent reduction in adults after 40 years of plant operation) of entrainment and impingement on the Hudson River striped bass population.

In assessing the impacts of multiple power plants located at different points along the Hudson River, it is essential that longitudinal spatial phenomena be explicitly considered through the use of a transport model. The vertical and lateral spatial phenomena, such as zone of withdrawal and vertical variations in distribution of ichthyoplankton, can be taken into account in a one-dimensional model by using empirical f factors, as has been done with the LMS 1-D model and the ORNL model (ref. 4). Use of a two- or three-dimensional model and a real time scale, as is now being done by Lawler, Matusky, and Skelly Engineers (ref. 6 and ref. 7, Sect. 12), is incompatible with the level of accuracy and detail of the available data. LMS have found that their one- and two-dimensional models give approximately the same answer, which provides yet another reason for relying on the LMS 1-D model (ref. 8, TR 319-322).

Age class zero (i.e., young of the year) in the LMS 1-D model is divided into five life stages: eggs, larvae, juvenile 1s (J1), juvenile 2s (J2), and juvenile 3s (J3). The first three of these life stages are considered to be entrainable, while the last two are impingeable.

The following power plants were included in doing model runs: Roseton, Units 1 and 2; Danokammer, Units 3 and 4; Indian Point, Units 2 and 3; Lovett, Units 4 and 5; Bowline, Units 1 and 2; and for some runs, the proposed Cornwall pump-storage facility.

The proposed Cornwall (Storm King) pump-storage facility has been included in some model runs since it is located (mile point 58) in the middle of the major striped bass spawning areas, water withdrawal is

appreciable (approximately 4000 cfs), and plans for this project are well past the formative stages. (In fact, construction was started, although it is not continuing at present.)

The following existing power plants were not taken into consideration in doing model runs: Albany; Danskammer, Units 1 and 2; Indian Point, Unit 1; Lovett, Units 1, 2, and 3; and 59th Street. These existing power plants, except Albany, were not included because in each case it is doubtful that the unit will be operating to a significant extent over the next 40 years. The Albany power plant, located at river mile 140, was not included because as presently designed the LMS 1-D model covers only river miles 10 to 130. Although entrainment of striped bass at Albany is not a problem, since striped bass rarely spawn above river mile 120, impingement of striped bass at Albany is a problem (see Sect. 5.5). This "oversight" by LMS in formulating the LMS 1-D model needs to be corrected.

The following proposed power plants and water project were not included: Greene County (closed-cycle, located at river mile 108, to be operated by the Power Authority of the State of New York); Mid Hudson (closed-cycle, between river miles 80 and 120, but specific site not chosen, to be operated by Consolidated Edison and others); New York State Gas and Electric (closed-cycle, between river miles 80 and 120, but specific site not chosen); and the Hudson River Project (i.e., high-flow skimming project) of the U.S. Army Corps of Engineers (between river miles 86 and 95).

These proposed power plants and the high-flow skimming project were not included because plans for these projects are still in the formative stages and because they would be upriver of the major striped bass spawning areas during most years. However, as at the Albany plant, impingement of yearling striped bass may be a problem, particularly for the high-flow skimming project, which would withdraw much more water than a power plant with closed-cycle cooling. Planning for these projects clearly does indicate that further water withdrawals that may further adversely affect the Hudson River striped bass population are being contemplated.

5.8.2 Input parameters and method of doing model runs

5.8.2.1 Power plant configurations and withdrawal rates. As input data, the LMS 1-D model requires values for power-plant water withdrawal rates by model segment. Water withdrawal rates for the individual plants, as well as for the groupings of plants into the various river segments in the model, are shown in Table 5.8.1. Because Albany is located upstream of the region considered in the model, it was not possible to include this plant in runs of the model as presently structured. The breakdown of withdrawal flows by type (once-through vs closed-cycle; service water vs condenser cooling water; makeup water vs nonmakeup water) was needed for subsequent derivation of values for segment withdrawal rates and composite f factors.

Table 5.8.1. Hudson River power plant intake flows (maximum and 90% of maximum)

Description ^a	Segment 10, Bowline		Segment 9						
	Unit 1	Unit 2	Lovett					Indian Point	
			Unit 1	Unit 2	Unit 3	Unit 4	Unit 5	Unit 2	Unit 3
Maximum intake flow (gpm)									
OT service water	8,000	8,000	1,000	1,000	1,000	2,000	2,000	30,000	30,000
OT condenser cooling water	376,000	376,000	25,144	25,144	42,206	104,168	119,883	840,000	840,000
OT total intake flow	384,000	384,000	26,144	26,144	43,206	106,168	121,883	870,000	870,000
CC nonmakeup service water	0	0						30,000	30,000
CC makeup water	8,000	8,000						26,000	31,000
CC total intake flow	8,000	8,000						56,000	61,000
90% intake flow (10 ⁶ m ³ /year)									
OT service water	14.3	14.3	1.79	1.79	1.79	3.58	3.58	53.7	53.7
OT condenser cooling water	673.3	673.3	45.0	45.0	75.6	186.5	214.7	1,504	1,504
OT total intake flow	688	688	46.8	46.8	77.4	190	218	1,558	1,558
CC nonmakeup service water	0	0						53.7	53.7
CC makeup water	14.3	14.3						46.6	55.5
CC total intake flow	14.3	14.3						100	109

Table 5.8.1 (continued)

Description ^a	Segment 8, Cornwall	Segment 7						Albany, Total
		Roseton		Danskommer				
		Unit 1	Unit 2	Unit 1	Unit 2	Unit 3	Unit 4	
Maximum intake flow (gpm)								
OT service water		12,000	12,000	764	764	3,240	6,850	7,500
OT condenser cooling water		308,500	308,000	42,000	42,000	78,760	143,150	352,000
OT total intake flow	1,975,000	320,500	320,500	42,764	42,764	82,000	150,000	359,500
CC nonmakeup service water		4,000	4,000					
CC makeup water		8,000	8,000					
CC total intake flow		12,000	12,000					
90% intake flow (10 ⁶ m ³ /year)								
OT service water		21.5	21.5	1.37	1.37	5.80	12.3	13.4
OT condenser cooling water		552	552	75.2	75.2	141	256.3	630.3
OT total intake flow	3,536	574	574	76.6	76.6	147	269	644
CC nonmakeup service water		7.16	7.16					
CC makeup water		14.3	14.3					
CC total intake flow		21.5	21.5					

Table 5.8.1 (Continued)

^aOT, once-through cooling; CC, closed-cycle cooling; conversion factor from gallons per minute (gpm) to million cubic meters per year is 0.0019896, not including the change from maximum intake flow to 90% intake flow.

Sources:

Bowline: (1) phone conversations with R. Metzger and W. Smith, Orange and Rockland Utilities, Inc., February 1977; (2) Ecological Analysts, Inc., *Bowline Point Generating Station. Entrainment Survival and Abundance Studies*, prepared for Orange and Rockland Utilities, Inc., vol. I, 1975 Annual Interpretive Report, July 1976, Table 1.2-2.; (3) Bechtel Associates Professional Corporation, *Natural Draft Cooling System Mitigating Measure Study*, prepared for Orange and Rockland Utilities, Inc., December 1974 (revised January 1975 and March 1975; preliminary) Chap. II, 1975.

Lovett: Lawler, Matusky, and Skelly Engineers, *1974 Hudson River Aquatic Ecology Studies - Bowline Point and Lovett Generating Stations*, prepared for Orange and Rockland Utilities, Inc., vol. I, December 1975, Table III-2.

Indian Point: (1) IP3 FES, vol. I, Chap. V, Table V-2, p. V-18; (2) IP3 FES, p. 9-1.

Roseton and Danskammer: (1) phone conversations with F. Dooris, Central Hudson Gas and Electric Corporation, February 1977; (2) ORNL assumes 8000 gpm closed-cycle makeup water for each of the two units at Roseton; this assumption is based on the similarity between the units at Roseton and Bowline and the value of 8000 gpm provided for each unit at Bowline.

Albany: personal communication with J. Columbek, U.S. Environmental Protection Agency, Region II, New York, February 1977 (based on information from the 316(a) Demonstration submitted to U.S. EPA by Niagara Mohawk Power Corporation for the Albany Steam-Electric Generating Station).

Cornwall: J. P. Lawler, "Testimony of Dr. John P. Lawler, Quirk, Lawler, and Matusky, on Effect of Entrainment and Impingement at Cornwall on the Hudson River Striped Bass Population," Testimony before the U.S. Federal Power Commission in the Matter of Consolidated Edison Company of New York, Inc., Project No. 2338 (Cornwall), October 1974.

Table 5.8.2 shows the flows actually input to the model by segment. Because model runs were done for a simulation period of 40 years, some of the older units (Danskammer Units 1 and 2 and Lovett Units 1, 2, and 3) were assumed not to be operating. In addition, it was assumed that, because of scheduled and unscheduled outages during the entrainment season, plants included in the runs would operate at an effective level of 90% of full flow during the entrainment season. While many of these units have the capability to operate with reduced flow rates for at least part of this period, it is not presently clear that they will do so or that entrainment mortality would not increase above assumed levels if they did. Values tabulated in Table 5.8.2 by power plant configuration and model river segment are calculated from maximum intake flow values in Table 5.8.1.

5.8.2.2 Form of the compensation function and levels of compensation. The compensation function in the LMS 1-D model has been described in Sect. 5.7.4 and is illustrated again in Fig. 5.8.1. Model runs for this report were done either with the function as originally developed and applied by LMS (left limb not disabled) or with an alternative form of the function, which, in the opinion of ORNL, has a more sound biological basis (left limb disabled; see Sect. 5.7.4). For these latter runs, the left limb was disabled for each young-of-the-year life stage (except eggs) by setting the cubic term in the equation given in Fig. 5.8.1 equal to zero whenever the concentration (or standing crop) at time t , $N(t)$, was less than the equilibrium concentration (or standing crop), YS . The resulting shape of the LMS compensation function when the left limb is disabled is indicated in Fig. 5.8.1.

The level of compensation is expressed as the ratio of the minimum mortality rate coefficient ($KX0$) to the equilibrium mortality rate coefficient (KX), or $KX0/KX$ (see Fig. 5.8.1). The higher this ratio, the less the effect of compensation; the maximum value considered ($KX0/KX = 1.0$) represents no compensation. Levels of compensation used, in order from no compensation to strong compensation, were 1.0, 0.95, 0.8, and 0.5. For any given model run, the same level of compensation was used for larvae and the three juvenile life stages considered in this model, namely, juvenile 1s (J1), juvenile 2s (J2), and juvenile 3s (J3). ORNL used the same set of YS and KX values as used by LMS (ref. 3 and Table 5.8.3), and $KX0$ was varied in order to achieve the desired level of compensation.

5.8.2.3 Levels of composite f factor. The LMS 1-D model requires that a composite f factor be specified for each entrainable life stage and each model river segment. The composite f factor is the product of the intake f factor (f_I) and the cropping factor (probability of entrainment mortality, or f_C). These factors are discussed in Sects. 5.4 and 5.3, respectively.

The first step in arriving at the input values is to estimate plant-specific f_C and f_I values for each entrainable life stage. Table 5.8.4 presents a summary of ORNL's current best estimates for cropping factors

Table 5.8.2. Power-plant water withdrawal rates by power-plant configuration and model river segment used as input to the LMS 1-D model

(Values in this table are calculated from values in Table 5.8.1 as follows: Values from the top half of Table 5.8.1 (i.e., maximum intake flows expressed in units of gpm) are multiplied by 1.307×10^{-9} to yield values in units of cubic miles per day, as required by the LMS model. These values were multiplied by 0.9 to allow for assumed outages (both scheduled and unscheduled) during the entrainment season and then summed to obtain withdrawal rates for the specific power-plant configuration and model river segment)

Configuration ^a	0.9 of maximum flow (cubic miles per day)				
	Segment 7: Roseton 1, 2; Danskammer 3, 4	Segment 8: Cornwall	Segment 9: Indian Point 2, 3; Lovett 4, 5	Segment 10: Bowline 1, 2	Total
1, all OT	1.02751E-03	0	2.31638E-03	9.03928E-04	4.24782E-03
2, all CC	3.01309E-04	0	4.06122E-04	1.88318E-05	7.26263E-04
3, Roseton CC	3.01309E-04	0	2.31638E-03	9.03928E-04	3.52161E-03
4, Indian Point CC	1.02751E-03	0	4.06122E-04	9.03928E-04	2.33756E-03
5, Bowline CC	1.02751E-03	0	2.31638E-03	1.88318E-05	3.36272E-03
6, all OT, with Cornwall	1.02751E-03	2.32456E-03	2.31638E-03	9.03928E-04	6.57237E-03
7, all CC, with Cornwall	3.01309E-04	2.32456E-03	4.06122E-04	1.88318E-05	3.05082E-03

^aOT, once-through condenser cooling; CC, closed-cycle condenser cooling; Cornwall pump-storage facility operating only when noted. In configurations 3, 4, and 5, plants not specifically identified have once-through condenser cooling.

Fig. 5.8.1. Form of the compensation function in the LMS 1-D model, with and without the left limb disabled. A function of this form is used for each of the striped bass young-of-the-year life stages, except eggs.

Table 5.8.3. Parameter values used by ORNL in its sensitivity analysis of the LMS compensation function

Parameter		Parameter value				
Symbol ^a	Units	Egg ^b	Larva	Juvenile 1	Juvenile 2	Juvenile 3
DTE	Days	1.5	28.0	30.0	149.5	158.0
KX	Day ⁻¹	1.535	0.06775	0.05365	0.005134	0.01065
YS						
Concentration	#/TCF ^c		70.0	18.0	3.50	2.62
Standing crop	Number of organisms		1.579E8 ^d	3.946E7 ^d	7.893E6 ^d	5.920E6 ^d

^aDTE, duration of the life stage; YS, saturation or equilibrium concentration (or standing crop); KX, equilibrium mortality rate coefficient; KX0, minimum mortality rate coefficient.

^bORNL and LMS assume that no compensation occurs in the egg stage.

^c#/TCF = number per thousand cubic feet.

^dFORTTRAN exponential notation; e.g., 1.579E8 = 1.579 x 10⁸.

Table 5.8 4. Summary of power-plant-specific f-factor values, by life-stage, for runs with the LMS model

f_I , intake f factor; f_c cropping factor (probability of entrainment mortality). ORNL estimates of f_c are based on Tables 5.3.12–5.3.15. At Indian Point, 1973 and 1974 data were combined by ORNL. Bowline and Roseton f_c values for post-yolk-sac larvae are based on 1975 data. For eggs, yolk-sac larvae, and juvenile ls, ORNL used Indian Point f_c values in the absence of any data or of adequate data for these stages at Bowline or Roseton. CEBE (Consolidated Edison's Best Estimate) values for f_c at Cornwall were used for all Cornwall runs. The sources for all CEBE values are: J. T. McFadden, ed., *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*, prepared for Consolidated Edison Company of New York, Inc., January 1977. Cornwall data are via personal communication between Kenneth Marcellus of Consolidated Edison and Webster Van Winkle of Oak Ridge National Laboratory, February 24, 1977. Reliable estimates of f_c , and CEBE values for both f_c and f_I , were not available for Lovett or Danskammer. The principles used to assign values to plants for which no data or inadequate data were available are described in the text. The ORNL values for f_I are either 0.5 or 1.0 in all cases. Composite f factors are obtained by multiplying f_c times f_I . "Combined larvae" f factors are obtained from the formula $(6 \times f_{YSL} + 22 \times f_{PYSL})/28$, where f_{YSL} is the f-factor value (either f_c or f_I) for yolk-sac larvae and f_{PYSL} is the corresponding f-factor value for post-yolk-sac larvae.

Life stage	f factor	f-factor level																	
		Bowline			Lovett			Indian Point			Cornwall			Roseton			Danskammer		
		ORNL		CEBE	ORNL		CEBE	ORNL		CEBE	ORNL		CEBE ^a	ORNL		CEBE	ORNL		CEBE
		Upper	Lower		Upper	Lower		Upper	Lower		Upper	Lower ²		Upper	Lower		Upper	Lower	
Egg	f_I	1.00	0.50	0.01	1.00	0.50	1.52	1.00	0.50	1.52	1.00	0.50	1.31	1.00	0.50	3.10	1.00	0.50	3.10
	f_c	0.71	0.71	0.49	0.71	0.71	0.49	0.71	0.71	0.49	0.45	0.45	0.45	0.71	0.71	0.49	0.71	0.71	0.49
	Composite	0.71	0.35	0.005	0.71	0.35	0.74	0.71	0.35	0.74	0.45	0.23	0.59	0.71	0.35	1.52	0.71	0.35	1.52
Larvae																			
Yolk-sac	f_I	1.00	0.50	0.14	1.00	0.50	0.45	1.00	0.50	0.45	1.00	0.50	0.80	1.00	0.50	0.64	1.00	0.50	0.64
	f_c	0.76	0.76	0.77	0.76	0.76	0.77	0.76	0.76	0.85	0.35	0.35	0.35	0.76	0.76	0.77	0.76	0.76	0.77
	Composite	0.76	0.38	0.11	0.76	0.38	0.35	0.76	0.38	0.38	0.35	0.17	0.28	0.76	0.38	0.49	0.76	0.38	0.49
Post-yolk-sac	f_I	1.00	0.50	0.28	1.00	0.50	0.37	1.00	0.50	0.37	1.00	0.50	0.91	1.00	0.50	1.06	1.00	0.50	1.06
	f_c	0.33	0.33	0.09	0.33	0.33	0.09	0.72	0.72	0.51	0.35	0.35	0.35	0.50	0.50	0.25	0.50	0.50	0.25
	Composite	0.33	0.17	0.03	0.33	0.17	0.03	0.72	0.36	0.19	0.35	0.17	0.32	0.50	0.25	0.27	0.50	0.25	0.27
Combined larvae	f_I	1.00	0.50	0.25	1.00	0.50	0.39	1.00	0.50	0.39	1.00	0.50	0.89	1.00	0.50	0.97	1.00	0.50	0.97
	f_c	0.42	0.42	0.24	0.42	0.42	0.24	0.73	0.73	0.58	0.35	0.35	0.35	0.55	0.55	0.36	0.55	0.55	0.36
	Composite	0.42	0.21	0.06	0.42	0.21	0.09	0.73	0.37	0.23	0.35	0.17	0.31	0.55	0.27	0.35	0.55	0.27	0.35
Juvenile 1	f_I	1.00	0.50	0.50	1.00	0.50	1.00	1.00	0.50	1.00	1.00	0.50	0.60	1.00	0.50	0.19	1.00	0.50	0.19
	f_c	0.69	0.69	0.16	0.69	0.69	0.16	0.59	0.69	0.16	0.55	0.55	0.55	0.69	0.69	0.16	0.69	0.69	0.16
	Composite	0.69	0.35	0.08	0.69	0.35	0.16	0.59	0.35	0.16	0.55	0.27	0.33	0.69	0.35	0.03	0.69	0.35	0.03

^aNot utilized in model runs.

for eggs, yolk-sac larvae, post-yolk-sac larvae, combined larvae, and juvenile ls at Indian Point, Bowline, and Roseton. These estimates were obtained from Tables 5.3.12-5.3.15 in the following manner:

1. For a given life stage and plant, an average initial estimate of f_C (denoted $f_{C,R}$) was obtained by averaging whatever "reliable" values were available from each of four categories: live only, initial conditions; live and stunned, initial conditions; live only, latent conditions; and live and stunned, latent conditions. "Latent" mortalities, prior to this averaging, were obtained by taking the average of the f_C value after 24 hr and the final f_C value (i.e., after 48 or 72 hr). In the case of eggs and some other stages at some power plants, four values were not available, and an average of the available data was taken.

2. The final estimate of f_C , denoted $\hat{f}_C$, was obtained as

$$\hat{f}_C = f_{C,R} + M(1 - f_{C,R}) , \quad (5.8-1)$$

where $f_{C,R}$ was obtained as explained above and M is an additional differential mortality assumed to occur to "survivors" of entrainment. For eggs and yolk-sac larvae, M was assigned a value of 0.1; for post-yolk-sac larvae and the juvenile 1 stage, a value of 0.25 was used. In part, M reflects that the immediate direct mortality (initial conditions) does not fully reflect all latent direct mortality that can be expected, and, in part, it reflects additional direct mortality that can be expected under conditions of full ΔT . The higher value for the later stages is used because ambient temperatures combined with full-power ΔT s may cause virtually complete mortality during some part of the period of occurrence of those stages.

3. At Indian Point, two years of data were available. An average of the two "final" estimates from step 2 was used for model runs.

4. For all stages except post-yolk-sac larvae, only Indian Point data were considered reliable enough to use. Estimates derived from the Indian Point data were therefore used at all plants for these stages.

5. Because the LMS 1-D model does not distinguish between yolk-sac larvae and post-yolk-sac larvae, an average of the f_C values for the two stages, weighted by the approximate duration of 6 days for yolk-sac larvae and 22 days for post-yolk-sac larvae, was used for "combined larvae" (see headnote of Table 5.8.4).

Table 5.8.4 also presents ORNL's interpretation of Consolidated Edison's current best-estimate f-factor values.

The f_C values in Table 5.8.4 represent estimates based on sampling organisms that have passed through power plants in either the (once-through) condenser cooling water system or the service water system. Separate survival estimates are not available for these two systems. We have assumed equal survival for purposes of this analysis. However,

it would be worth while to collect more information on survival through the service water system. To the extent that survival through the condenser cooling water system appears relatively higher than formerly assumed, comparisons between once-through and closed-cycle systems are increasingly influenced by survival through the service water system. For example, Consolidated Edison assumes 91% survival of post-yolk-sac larvae through Bowline. If this were true, if mortality in the service water system were 100%, and if the service water represented 9% of the total once-through intake flow, then 100% survival through the condenser could be inferred. Consequently, the entrainment impact on this life stage could be the same for closed-cycle as for open-cycle cooling. The example is merely hypothetical and is intended to stimulate further thought and investigation on the topic.

Service water requirements were assumed not to change for closed-cycle cooling. Necessary makeup water for the closed-cycle system was assumed to be the same (8000 gpm per unit) at Roseton as at Bowline and was assumed to be supplied by the service water system at both plants. Survival in the 4000 gpm of service water per unit at Roseton that is not needed for makeup water was assumed to be the same as estimated for the present once-through cooling system. Complete mortality of organisms in water needed for makeup was assumed. Intake f_I values for Danskammer were assumed to be the same as used for Roseton, and f_I values for Lovett were assumed to be the same as used for Indian Point. In both cases, geographical proximity was assumed most important. Cropping factor values (f_C) estimated for Roseton were used for Danskammer, while f_C estimates for Bowline were used for Lovett. Bowline f_C values were used for Lovett because the similarity of residence time of withdrawn water was felt to be more important than the geographical considerations. In all model runs involving Cornwall, Consolidated Edison's current best-estimate values for the cropping factor at Cornwall were used.

The life-stage-specific segment composite f factors needed as input to the model (Table 5.8.5) were calculated using Tables 5.8.1 and 5.8.4, in conjunction with the assumptions mentioned above. Calculations of the composite f -factor values considered the plant-specific f_I and f_C values (including the type of water, that is, $f_C = 1.0$ for makeup water). Three levels of composite f factors were considered. The first used Consolidated Edison's current best estimates for both f_I and f_C . The second used 0.5 as a constant estimate of f_I in combination with ORNL's current best-estimate cropping factor (f_C values). The third level used 1.0 as a constant estimate of f_I in combination with ORNL's current best-estimate f_C values.

The completely mixed portion of the LMS 1-D model requires specification of a single composite f factor for the entire system for each entrainable life stage. These values (Table 5.8.6) were obtained by multiplying each segment composite f factor (Table 5.8.5) by the corresponding total segment withdrawal (Table 5.8.2), summing these products, and dividing the total by the total system water withdrawal.

Table 5.8.5. Segment composite f factors used as input to the LMS 1-D model

("Composite" means the product of f_I , the intake f factor, and f_C , the cropping factor (probability of entrainment mortality). Values in this table are obtained using values from Tables 5.8.1 and 5.8.4, using the method described in the text)

Segment	f-factor ^a level	Configuration ^b	Composite f factor		
			Eggs	Larvae	Juvenile ls
7	CE	OT	1.519	0.350	0.030
		CC	1.618	0.389	0.040
	0.5f _C	OT	0.355	0.275	0.345
		CC	0.364	0.289	0.355
	1.0f _C	OT	0.710	0.550	0.690
		CC	0.728	0.578	0.709
8	1.0f _C	IN	0.450	0.350	0.550
9	CE	OT	0.745	0.211	0.160
		CC	0.873	0.164	0.299
	0.5f _C	OT	0.355	0.347	0.345
		CC	0.379	0.285	0.371
	1.0f _C	OT	0.710	0.694	0.690
		CC	0.758	0.570	0.741
10	CE	OT	0.005	0.059	0.080
		CC	0.010	0.249	0.500
	0.5f _C	OT	0.355	0.210	0.345
		CC	0.500	0.500	0.500
	1.0f _C	OT	0.710	0.420	0.690
		CC	1.000	1.000	1.000

^aCE means Consolidated Edison's current best-estimate f-factor values (Table 5.8.4); 0.5f_C means $f_I = 0.5$ and f_C is as given in Table 5.8.4; 1.0f_C means $f_I = 1.0$ and f_C is as given in Table 5.8.4.

^bOT means that all units at all power plants in the indicated segment were operating in the model run with once-through condenser cooling; CC means that both units of the "subject" power plant within the indicated segment were operating in the model run with closed-cycle cooling (i.e., Roseton Units 1, 2 in segment 7; Indian Point Units 2, 3 in segment 9; and Bowline Units 1, 2 in segment 10), while all units at the other power plant (if present) in the indicated segment were operating in the model run with once-through condenser cooling. (i.e., Danskammer Units 3, 4 in segment 7; Lovett Units 4, 5 in segment 9); IN means Cornwall pump-storage facility operating (composite f factor for segment 8 is zero when Cornwall is not operating).

Table. 5.8.6. System composite f factors used as input to the completely mixed portion of the LMS 1-D model

("Composite" means the product of f_I , the intake f factor, and f_C , the cropping factor, or probability of entrainment mortality. Values in this table were obtained using values from Tables 5.8.1 and 5.8.5, using the method described in the text)

Configuration ^a	Composite f-factor level								
	Consolidated Edison best estimate ^b			0.5 f_C ^c			1.0 f_C ^d		
	Egg	Larvae	Juvenile 1	Egg	Larvae	Juvenile 1	Egg	Larvae	Juvenile 1
1, all OT	0.775	0.212	0.112	0.355	0.300	0.345	0.710	0.601	0.690
2, all CC	1.160	0.259	0.197	0.376	0.292	0.367	0.752	0.584	0.735
3, Roseton CC	0.630 ^e	0.187 ^e	0.129 ^e	0.356 ^e	0.307 ^e	0.346 ^e	0.712	0.614	0.692
4, Indian Point CC	0.821 ^e	0.205 ^e	0.096 ^e	0.359 ^e	0.252 ^e	0.349 ^e	0.718	0.503	0.699
5, Bowline CC	0.977 ^e	0.253 ^e	0.122 ^e	0.356 ^e	0.326 ^e	0.346 ^e	0.712	0.652	0.692
6, Cornwall; all OT							0.618	0.512	0.640
7, Cornwall; all CC							0.522	0.406	0.594

^aOT, once-through condenser cooling (see footnote b in Table 5.8.5); CC, closed-cycle condenser cooling (see footnote b in Table 5.8.5); Cornwall pump-storage facility operating only when noted. In configurations 3, 4, and 5, plants not specifically mentioned have once-through condenser cooling.

^bBased on Consolidated Edison's current best-estimate f-factor values (Table 5.8.4).

^c f_I assumed to equal 0.5 and f_C based on Table 5.8.4.

^d f_I assumed to equal 1.0 and f_C based on Table 5.8.4.

^eNot utilized in this series or runs.

5.8.2.4 Numbers of juvenile 2s and 3s impinged. The LMS 1-D model accepts as input a number of fish to be impinged for each of the juvenile 2 and juvenile 3 stages in each segment. The starting point for determination of these numbers is the estimated number of striped bass impinged annually at each power plant under specified operating conditions. These estimates are given in Table 5.5.7. These values are then combined to give number of juvenile 2s and 3s to be impinged by segment and by power-plant configuration (Table 5.8.7).

Two adjustments are needed before model input values can be specified. The first adjustment relates the model population size to the assumed true population size in the river. Thus, if the size of the fish population in the model is twice the true population size, it is necessary to impinge twice as many fish in the model population in order for the percentage reduction value to be accurate. The best available estimates of the size of the young-of-the-year striped bass population are for the period August through about November (refs. 7 and 9). A reasonable range of estimates of the size of the population during this period is between 1,000,000 and 10,000,000 juveniles; we chose 5,000,000 as a base number for comparison with the model. A reasonable index of the model population size during this period can be obtained by averaging the production into the juvenile 2 and the juvenile 3 stages. The size of this model index, obtained from preliminary model runs, ranged between about 6,000,000 and 7,000,000 fish, depending on the level of compensation. Thus, the initial set of "scaling factors" resulted in "target" impingement values, T_1 , approximately 1.2 to 1.4 times the numbers in Table 5.8.7.

The need for a second adjustment arises because of a substantial lack of correspondence between the input numbers, T_1 , and the numbers actually impinged in the model. In general, the model consistently impinges fewer fish than are input, although the relationship is somewhat erratic, depending on many factors, including the life stage, river segment, level and form of compensation, and magnitude of water withdrawals. From further preliminary runs using the "target" impingement values, T_1 , "correction factors" of 2.04 for the juvenile 2 stage and 1.53 for the juvenile 3 stage were calculated. These factors were applied to the T_1 values mentioned above to give "corrected target" impingement values, T_2 .

For reasons that are not presently understood, use of these "corrected target" impingement values, T_2 , in a case with strong compensation (i.e., $KX0/KX$ of 0.5) and once-through configurations resulted in aberrant behavior of the model. The "impingement f factor" calculated by the model for juvenile 3s in segment 7 was negative (fish were added to the system), and fish disappeared from all other segments. It was found that the runs could be done successfully if all the "scaling factors" (see above) were divided by 2. This set of "revised scaling factors" was then 0.6265, 0.6235, 0.6420, and 0.7100 for values of $KX0/KX$ (compensation levels) of 1.0, 0.95, 0.8, and 0.5 respectively. The effect of using these revised scaling factors was to yield a set of

Table 5.8.7. Estimated number of striped bass impinged annually by river segment for each of seven power plant configurations

(Values are calculated from values in Table 5.5.6 according to the method described in the text. Values are given for juvenile 2 (J2), juvenile 3 (J3), and J2 and J3 combined)

Configuration ^a					Stage	Segment 7	Segment 8	Segment 9	Segment 10
Code	Bowline	Indian Point	Roseton	Cornwall					
1	OT	OT	OT	-	Total	10,822		56,055	128,187
					J2	7,737		12,369	5,103
					J3	3,085		43,686	123,084
2	CC	CC	CC	-	Total	8,173		17,874	3,187
					J2	6,078		3,318	119
					J3	2,095		14,556	3,068
3	OT	OT	CC	-	Total	8,173		56,055	128,187
					J2	6,078		12,369	5,103
					J3	2,095		43,686	123,084
4	OT	CC	OT	-	Total	10,822		17,874	128,187
					J2	7,737		3,318	5,103
					J3	3,085		14,556	123,084
5	CC	OT	OT	-	Total	10,822		56,055	3,187
					J2	7,737		12,369	119
					J3	3,085		43,686	3,068
6	OT	OT	OT	+	Total	10,822	74,781	56,055	128,187
					J2	7,737	26,336	12,369	5,103
					J3	3,085	48,445	43,686	123,084
7	CC	CC	CC	+	Total	8,173	74,781	17,874	3,187
					J2	6,078	26,336	3,318	119
					J3	2,095	48,445	14,556	3,068

^aOT, once-through condenser cooling; CC, closed-cycle condenser cooling; - and + mean Cornwall pump storage facility not operating and operating respectively.

"corrected-corrected target" impingement values, $T_3 (= T_2/2)$. This approach was used for all model runs presented in this report. Conceptually, it corresponds either to assuming a river population on the order of 10,000,000 juveniles during the fall (rather than the 5,000,000 originally chosen as a base number) or to assuming a 100% impingement collection efficiency (rather than 50%) at all the power plants. This approach of inputting T_3 values, in comparison with the original approach of inputting T_2 values, results in somewhat lower percentage reduction values and a somewhat lowered importance for impingement relative to entrainment as a source of impact.

The numbers input to the model to control impingement are presented in Table 5.8.8. Examination of the number of fish actually impinged in selected runs showed that, in most cases, actual total impingement was between 85% and 115% of the "corrected-corrected target" impingement value, T_3 . Substantially larger discrepancies occur within any of the runs when individual stages and segments are examined. Occasionally, clear patterns emerge. For example, juvenile 3s in segment 7 are consistently overimpinged, while juvenile 2s in segment 10 are consistently underimpinged. Taken as a whole, these discrepancies introduce a modest amount of both bias and variation into the comparisons discussed in the next section (Sect. 5.8.3). These effects are not felt to be strong enough to invalidate the fundamental conclusions of the study.

5.8.3 Results of model runs

The results of the 56 runs of the LMS one-dimensional transport model for the Hudson River striped bass population are summarized in Table 5.8.9. Values from this reference table have been plotted in Figs. 5.8.2 through 5.8.7 to highlight certain effects and have been retabulated in Tables 5.8.10 through 5.8.18 in order to summarize results separately for each configuration.

5.8.3.1 Left limb disabled vs left limb not disabled. Forty-four out of the 56 runs were done with the left limb of the LMS compensation function disabled, while the remaining 12 runs were done with the left limb not disabled. None of the results from the 12 runs have been included in any of the figures. For these 12 runs, the mean percentage reduction for yearlings after one year of plant operation is 6.8%, and the mean percentage reduction for the adult population after 40 years of plant operation is 18.2%. The corresponding two means for the corresponding 12 runs with the left limb disabled are 7.9 and 32.9% respectively. The differences in percentage reduction of adults after 40 years rather dramatically indicate the point made in Sect. 5.7.4 that disabling the left limb results in appreciably higher estimates of percentage reduction.

5.8.3.2 Compensation. Figures 5.8.2 through 5.8.5 illustrate the effect of different levels of compensation as given by the ratio $KX0/KX$. Again, $KX0/KX = 1.0$ represents no compensation, while $KX0/KX = 0.5$

Table 5.5.8. Numbers used as input to the LMS 1-D model to control the number of fish impinged

(These numbers are obtained from Table 5.8.7 after sequential multiplication by the appropriate revised "scaling factor" (0.6265, 0.6235, 0.6420, and 0.7100 for values of KX0/KX of 1.0, 0.95, 0.8, and 0.5 respectively) and the appropriate correction factor (2.04 for juvenile 2 and 1.53 for juvenile 3 respectively). These factors are explained in the text. KX0/KX, level of compensation)

Segment	Configuration ^a	Stage ^b	KX0/KX = 1.0	KX0/KX = 0.95	KX0/KX = 0.8	KX0/KX = 0.5
7	OT	J2	9,885	9,841	10,133	11,207
		J3	2,957	2,943	3,031	3,351
	CC	J2	7,768	7,731	7,960	8,803
		J3	2,008	1,999	2,058	2,276
	In	J2	33,655	33,498	34,491	31,845
		J3	46,437	46,216	47,585	52,626
8	Nct in	J2	0	0	0	0
		J3	0	0	0	0
	OT	J2	15,805	15,733	16,199	17,915
		J3	41,875	41,675	42,911	47,456
	CC	J2	4,241	4,221	4,345	4,806
		J3	13,953	13,886	14,298	15,812
10	OT	J2	6,522	6,491	6,683	7,391
		J3	117,981	117,417	120,901	113,706
	CC	J2	152	151	156	173
		J3	2,945	2,927	3,013	3,333

^aOT, once-through condenser cooling; CC, closed-cycle condenser cooling at the "subject" plants; "in" and "not in" mean Cornwall pump-storage facility operating and not operating respectively.

^bJ2, juvenile 2 stage; J3, juvenile 3 stage.

Table 5.8.9. Summary of percent reduction values using the LMS 1-D model

Each entry of this table consists of three numbers. The first number is the code number for the model run; the second number is the percent reduction in yearlings after one year of plant operation; the third is the percent reduction of the adult population (age classes 1-14) after 40 years of plant operation.

Power plant configurations 1-5 are without Cornwall; configurations 6 and 7 are the same as configurations 1 and 2 but with Cornwall operating. B, Bowline; IP, Indian Point; R, Roseton. OT, once-through cooling; CC, closed-cycle cooling.

LLD, left limb of the LMS compensation function disabled; LLND, left limb not disabled.

		Without Cornwall						With Cornwall		
		Configuration 1:		Configuration 2:		Configuration 3:	Configuration 4:	Configuration 5:	Configuration 6:	Configuration 7:
Compensation ratio, KX_0/KX^a	Composite f factor ^b	B, OT; R, OT	IP, OT;	B, CC; R, CC	IP, CC;	B, OT; IP, OT; R, CC	B, OT; IP, CC; R, OT	B, CC; IP, OT; R, OT	B, OT; IP, OT; R, OT	B, CC; IP, CC; R, CC
		LLD	LLND	LLD	LLND					
1.0	1.0f _C	SWC421		SWC422		SWC423	SWC424	SWC425	SWC426	SWC427
		29.7		5.41		27.7	20.6	18.0	38.2	15.9
		86.2		27.0		83.9	72.8	67.4	93.3	62.5
	0.5f _C	SWC411		SWC412						
		20.0		3.24						
		71.7		17.0						
	CEBE	SWC401		SWC402						
		14.2		2.85						
		57.9		15.1						
0.95	1.0f _C	SWC321	DLD321	SWC322	DLD322	SWC323	SWC324	SWC325	SWC326	SWC327
		21.2	20.0	3.39	3.23	19.6	13.7	11.6	29.5	10.7
		73.6	62.9	17.6	13.8	70.3	56.1	49.9	85.6	46.9
	0.5f _C	SWC311		SWC312						
		14.1		2.21						
		57.2		11.8						
	CEBE	SWC301	DLD301	SWC302	DLD302					
		10.7	10.2	1.93	1.91					
		46.9	38.1	10.6	8.37					
0.8	1.0f _C	SWC221	DLD221	SWC222	DLD222	SWC223	SWC224	SWC225	SWC226	SWC227
		15.2	12.1	2.55	2.31	14.1	9.89	7.92	22.1	7.94
		59.8	28.5	13.3	6.24	56.6	43.7	36.6	74.7	36.7

Table 5.8.9 (continued)

		Without Cornwall						With Cornwall		
		Configuration 1:		Configuration 2:		Configuration 3:	Configuration 4:	Configuration 5:	Configuration 6:	Configuration 7:
Compensation ratio, KX_0/KX^a	Composite f factor ^b	B, OT; R, OT	IP, OT;	B, CC; R, CC	IP, CC;	B, OT; IP, OT; R, CC	B, OT; IP, CC; R, OT	B, CC; IP, OT; R, OT	B, OT; IP, OT; R, OT	B, CC; IP, CC; R, CC
		LLD	LLND	LLD	LLND					
0.5	0.5f _C	SWC211 11.2 43.1		SWC212 1.86 9.89						
	CEBE	SWC201 9.61 42.7	DLD201 8.44 21.0	SWC202 1.72 9.13	DLD202 1.66 4.53					
	1.0f _C	SWC121 13.5 54.8	DLD121 9.67 14.7	SWC122 2.43 12.6	DLD122 2.26 3.72	SWC123 12.7 52.3	SWC124 9.44 41.8	SWC125 6.67 31.5	SWC126 19.2 68.6	SWC127 7.06 33.0
	0.5f _C	SWC111 11.2 47.7		SWC112 1.92 10.1						
	CEBE	SWC101 10.3 44.7	DLD101 8.27 13.1	SWC102 1.80 9.48	DLD102 1.88 3.11					

^a KX_0/KX is the ratio of the minimum to the equilibrium mortality rate and is a measure of the strength of the compensation function of larvae, juvenile 1s, juvenile 2s, and juvenile 3s, ranging from no compensation (1.0) to strong compensation (0.5).

^bThe composite f factor is the product of the intake f factor, f_I , and the cropping factor, f_C . 1.0f_C means that f_I was taken to be 1.0 for eggs, larvae, and juvenile 1s at all power plants. 0.5f_C means that f_I was taken to be 0.5 for eggs, larvae, and juvenile 1s at all power plants. CEBE, Consolidated Edison best-estimate composite f factors. See Table 5.8.5 for a tabulation of the f-factor values actually used.

Table 5.8.10. Model impact predictions for all plants operating with once-through cooling, without Cornwall (configuration 1), left limb of compensation function disabled

Level of compensation (KX0/KX)	Percentage reduction for the indicated composite f-factor level					
	Yearlings (year 1)			Adults (year 40)		
	1.0f _c	0.5f _c	CEBE	1.0f _c	0.5f _c	CEBE
1.0 (none)	29.7	20.0	14.2	86.2	71.7	57.9
0.95 (low)	21.2	14.1	10.7	73.6	57.2	46.9
0.80 (high)	15.2	11.2	9.61	59.8	48.1	42.7
0.50 (higher)	13.5	11.2	10.3	54.8	47.7	44.7

Table 5.8.11. Model impact predictions for all plants operating with closed-cycle cooling, without Cornwall (configuration 2), left limb of compensation function disabled

Level of compensation (KX0/KX)	Percentage reduction for the indicated composite f-factor level					
	Yearlings (year 1)			Adults (year 40)		
	1.0f _c	0.5f _c	CEBE	1.0f _c	0.5f _c	CEBE
1.0 (none)	5.41	3.24	2.85	27.0	17.0	15.1
0.95 (low)	3.39	2.21	1.98	17.6	11.8	10.6
0.80 (high)	2.55	1.86	1.72	13.3	9.89	9.13
0.50 (higher)	2.43	1.92	1.80	12.6	10.1	9.48

Table 5.8.12. Model impact predictions for Roseton operating with closed-cycle cooling, all other plants operating with once-through cooling, without Cornwall (configuration 3), left limb of compensation function disabled

Level of compensation (KX0/KX)	Percentage reduction for the indicated composite f-factor level					
	Yearlings (year 1)			Adults (year 40)		
	$1.0f_c$	$0.5f_c$	CEBE	$1.0f_c$	$0.5f_c$	CEBE
1.0 (none)	27.7	<i>a</i>	<i>a</i>	83.9	<i>a</i>	<i>a</i>
0.95 (low)	19.6	<i>a</i>	<i>a</i>	70.3	<i>a</i>	<i>a</i>
0.80 (high)	14.1	<i>a</i>	<i>a</i>	56.6	<i>a</i>	<i>a</i>
0.50 (higher)	12.7	<i>a</i>	<i>a</i>	52.3	<i>a</i>	<i>a</i>

^aRuns not done.

Table 5.8.13. Model impact predictions for Indian Point operating with closed-cycle cooling, all other plants operating with once-through cooling, without Cornwall (configuration 4), left limb of compensation function disabled

Level of compensation (KX0/KX)	Percentage reduction for the indicated composite f-factor level					
	Yearlings (year 1)			Adults (year 40)		
	$1.0f_c$	$0.5f_c$	CEBE	$1.0f_c$	$0.5f_c$	CEBE
1.0 (none)	20.6	<i>a</i>	<i>a</i>	72.8	<i>a</i>	<i>a</i>
0.95 (low)	13.7	<i>a</i>	<i>a</i>	56.1	<i>a</i>	<i>a</i>
0.80 (high)	9.89	<i>a</i>	<i>a</i>	43.7	<i>a</i>	<i>a</i>
0.50 (higher)	9.44	<i>a</i>	<i>a</i>	41.8	<i>a</i>	<i>a</i>

^aRuns not done.

Table 5.8.14. Model impact predictions for Bowline operating with closed-cycle cooling, all other plants operating with once-through cooling, without Cornwall (configuration 5), left limb of compensation function disabled

Level of compensation (KX0/KX)	Percentage reduction for the indicated composite f-factor level					
	Yearlings (year 1)			Adults (year 40)		
	$1.0f_c$	$0.5f_c$	CEBE	$1.0f_c$	$0.5f_c$	CEBE
1.0 (none)	18.0	a	a	67.4	a	a
0.95 (low)	11.6	a	a	49.9	a	a
0.80 (high)	7.92	a	a	36.6	a	a
0.50 (higher)	6.67	a	a	31.5	a	a

^aRuns not done.

Table 5.8.15. Model impact predictions for all plants operating with once-through cooling, with Cornwall (configuration 6), left limb of compensation function disabled

Level of compensation (KX0/KX)	Percentage reduction for the indicated composite f-factor level					
	Yearlings (year 1)			Adults (year 40)		
	1.0f _c	0.5f _c	CEBE	1.0f _c	0.5f _c	CEBE
1.0 (none)	38.2	a	a	93.3	a	a
0.95 (low)	29.5	a	a	85.6	a	a
0.80 (high)	22.1	a	a	74.7	a	a
0.50 (higher)	19.2	a	a	68.6	a	a

^aRuns not done.

Table 5.8.16. Model impact predictions for all plants operating with closed-cycle cooling, with Cornwall (configuration 7), left limb of compensation function disabled

Level of compensation (KX0/KX)	Percentage reduction for the indicated composite f-factor level					
	Yearlings (year 1)			Adults (year 40)		
	$1.0f_c$	$0.5f_c$	CEBE	$1.0f_c$	$0.5f_c$	CEBE
1.0 (none)	15.9	a	a	62.5	a	a
0.95 (low)	10.7	a	a	46.9	a	a
0.80 (high)	7.94	a	a	36.7	a	a
0.50 (higher)	7.06	a	a	33.0	a	a

^aRuns not done.

Table 5.8.17. Model impact predictions, with left limb of compensation function not disabled, for all plants operating with once-through cooling, without Cornwall (configuration 1); without compensation, results with the left limb not disabled are the same as with the left limb disabled

Level of compensation (KX0/KX)	Percentage reduction for the indicated composite f-factor level					
	Yearlings (year 1)			Adults (year 40)		
	1.0f _c	0.5f _c	CEBE	1.0f _c	0.5f _c	CEBE
1.0 (none)	29.7	20.0	14.2	86.2	71.7	57.9
0.95 (low)	20.0	a	10.2	62.9	a	38.1
0.80 (high)	12.1	a	8.44	28.5	a	21.0
0.50 (higher)	9.67	a	8.27	14.7	a	13.1

^aRuns not done.

Table 5.8.18. Model impact predictions, with left limb of compensation function not disabled, for all plants operating with closed-cycle cooling, without Cornwall (configuration 2); without compensation, results with the left limb not disabled are the same as with the left limb disabled

Level of compensation (KX0/KX)	Percentage reduction for the indicated composite f-factor level					
	Yearlings (year 1)			Adults (year 40)		
	$1.0f_c$	$0.5f_c$	CEBE	$1.0f_c$	$0.5f_c$	CEBE
1.0 (none)	5.41	3.24	2.85	27.0	17.0	15.1
0.95 (low)	3.23	α	1.91	13.8	α	8.37
0.80 (high)	2.31	α	1.66	6.24	α	4.53
0.50 (higher)	2.26	α	1.88	3.72	α	3.11

α Runs not done.

ES-3649

Fig. 5.8.2. Percentage reduction in number of yearlings at year 1 as a function of the level of compensation ($KX0/KX$) for each of three sets of the composite f factor; configuration 1 (i.e., Roseton, Indian Point, and Bowline with once-through cooling).

Fig. 5.8.3. Percentage reduction in number of yearlings at year 1 as a function of the level of compensation ($KX0/KX$) for each of three sets of the composite f factor; configuration 2 (i.e., Roseton, Indian Point, and Bowline with closed-cycle cooling).

ES-3651

Fig. 5.8.4. Percentage reduction in number of adults at year 40 as a function of the level of compensation ($KX0/KX$) for each of three sets of the composite f factor; configuration 1 (i.e., Roseton, Indian Point, and Bowline with once-through cooling).

ES-3652

Fig. 5.8.5. Percentage reduction in number of adults at year 40 as a function of the level of compensation ($KX0/KX$) for each of three sets of the composite f factor; configuration 2 (i.e., Roseton, Indian Point, and Bowline with closed-cycle cooling).

represents strong compensation. Percentage reduction in number of yearlings after one year of plant operation is plotted in Fig. 5.8.2 (configuration 1; once-through cooling at Bowline, Indian Point, and Roseton) and Fig. 5.8.3 (configuration 2; closed-cycle cooling at Bowline, Indian Point, and Roseton), while percentage reduction in the total adult population after 40 years of plant operation is plotted in Figs. 5.8.4 and 5.8.5 for the same two power plant configurations. Regardless of the set of f factors used, the curves in each of these four figures indicate the same general pattern. This pattern is that estimates of percentage reduction are relatively insensitive to the value of $KX0/KX$ over the range 0.5 to 0.8 but increase by a factor of 1.5 to 2.0 between 0.8 and 1.0, with most of that increase coming between 0.95 and 1.0. The same pattern was found with the LMS completely mixed model and is discussed in ref. 10.

In contrast to applications of this model by Lawler, Matusky and Skelly Engineers, substantial percentage reduction values are attained even with high levels of compensation (e.g., approximately 10% for yearlings at year 1 and more than 40% for adults at year 40). Furthermore, when high levels of compensation are used, percentage reduction values are relatively insensitive to the composite f -factor level used for the three entrainable life stages. These results reflect the effects of impingement, which occurs independently of the f -factor level and primarily in the juvenile-3 stage, by which time there is little opportunity for compensation in the model within that year to offset impingement mortality. Impingement rates in the present application are higher than those used by Lawler, Matusky and Skelly Engineers (see Sect. 5.8.2.4), and thus percentage reduction values in present runs are correspondingly higher, reflecting a greater relative importance of impingement.

5.8.3.3 Composite f factor. The effect of three different levels of composite f factors on percentage reduction of yearlings after one year and on percentage reduction of adults after 40 years is also illustrated in Figs. 5.8.2 through 5.8.5. As expected, the highest level of f factors ($1.0f_C$) result in the highest percentage reductions, while Consolidated Edison's best-estimate f factors (CEBE) result in the lowest percentage reductions. The $0.5f_C$ level results in percentage reductions somewhat closer to the CEBE percentage reductions than to the $1.0f_C$ percentage reductions. These four figures also illustrate that the effect of different levels of composite f factors is decreased when there is a high level of compensation, that is, the three curves in each of these four figures are closest together at $KX0/KX = 0.5$ and are farthest apart at $KX0/KX = 1.0$. At $KX0/KX = 1.0$, estimates of percentage reduction for CEBE and for $1.0f_C$ differ by a factor of about 1.5 to 2.0. Thus, both for compensation and for the composite f factor, the ratio of maximum to minimum estimate of percentage reduction differs by a factor of 1.5 to 2.0. Considering these two variables in combination, the ratio can differ by more than a factor of 2.0. In particular, the ratios (percentage reduction at $KX0/KX = 1.0$ and $1.0f_C$) / (percentage reduction at $KX0/KX = 0.5$ and CEBE f factor) are 2.9 (Fig. 5.8.2),

3.0 (Fig. 5.8.3), 1.9 (Fig. 5.8.4), and 2.8 (Fig. 5.8.5). The point to be made here is that none of the compensation levels or f-factor levels used in this sensitivity analysis can be completely discredited; adequate data are just not available. The effect of uncertainties in these input parameters is reflected in turn by estimates of percentage reduction that can differ by as much as a factor of 2.0 to 3.0.

5.8.3.4 Tabulation of results by configuration. Results from the 56 runs of the LMS 1-D model given in Table 5.8.9 are retabulated in Tables 5.8.10 through 5.8.16 for each of the seven power-plant configurations with the left limb of the compensation function disabled and in Tables 5.8.17 and 5.8.18 for configurations 1 and 2 with the left limb of the compensation function not disabled. These tables are included for reference purposes only, and the reader is referred to the preceding subsections of Sect. 5.8.3 for discussion of these results.

5.8.3.5 Relative importance of entrainment and impingement. The relative importance of entrainment and impingement to predictions of percentage reduction from the model depends on both the assumed level of compensation, the particular power plant configuration being considered, and the measure chosen for evaluating the impact (yearlings at year 1 or adults at year 40). With no compensation and all plants operating with once-through cooling, impingement accounts for less than one-fourth of the maximum predicted impact on yearlings (Table 5.8.19), although the operation of impingement alone would cause an impact on adults at year 40 more than one-third as large as the combined effect of impingement and full entrainment. (Table 5.8.19 also illustrates the important point that the effects of entrainment and impingement are not additive, even in the absence of compensation. To some extent, the problems involved in controlling the numbers of fish impinged in the model also influence these results.) In contrast to the results just described, impingement becomes substantially more important than entrainment when a strong level of compensation is assumed (Table 5.8.20). This occurs because most of the compensatory period precedes the impingement period. Thus, while strong compensation can largely offset the effects of entrainment, it is relatively ineffective in offsetting the effects of impingement. The fact that eliminating impingement in the strong compensation case (second vs first entry under configuration 1 for yearlings in Table 5.8.20) causes a larger absolute decrease in percent reduction than eliminating impingement in the comparable case without compensation (Table 5.8.19) is likely an artifact of the failure of the model to achieve the target impingement levels.

An examination of Table 5.8.20 also reveals that the relative importance of entrainment vs impingement depends on the cooling system configuration being considered. For example, removing impingement from the model has a relatively smaller effect in configuration 5 because, in that case, full impingement has already been reduced relative to other configurations since Bowline is assumed to be operating with closed-cycle cooling. Conversely, removing entrainment with configuration 5 has a relatively larger effect than removing entrainment with configurations

Table 5.8.19. Comparison of the relative importance of entrainment and impingement to percentage-reduction predictions for a case with no compensation and all plants operating with once-through cooling (configuration 1)

Level of entrainment	Level of impingement	Percentage reduction in yearlings (year 1)	Percentage reduction in adults (year 40)
Full ($1.0f_c$)	Full	29.7	86.2
Full ($1.0f_c$)	None	24.9	80.1
Half ($0.5f_c$)	Full	20.0	71.7
Low (CEBE)	Full	14.2	57.9
None	Full	6.4	31.2

Table 5.3.20. Comparison of the relative importance of entrainment and impingement to percentage-reduction predictions for cases with strong compensation ($KX0/KX = 0.5$) for various power-plant configurations

(All runs done with left limb of compensation function disabled. Cornwall is not included in any of these runs)

Level of entrainment	Level of impingement	Percentage reduction in yearlings (year 1)					Percentage reduction in yearlings (year 40)				
		Configuration ^a									
		1	2	3	4	5	1	2	3	4	5
Full ($1.0f_c$)	Full	13.5	2.43	12.7	9.44	6.67	54.8	12.5	52.3	41.8	31.5
Full ($1.0f_c$)	None	5.15	1.09	4.33	2.17	4.17	25.1	5.32	21.5	11.3	20.8
Half ($0.5f_c$)	Full	11.2	1.92	<i>b</i>	<i>b</i>	<i>b</i>	47.7	10.1	<i>b</i>	<i>b</i>	<i>b</i>
Low (CEBE)	Full	10.3	1.80	<i>b</i>	<i>b</i>	<i>b</i>	44.7	9.48	<i>b</i>	<i>b</i>	<i>b</i>
None	Full	8.7	1.4	8.6	7.4	2.8	39.3	7.3	39.0	34.2	14.3

^aKey to configurations:

Method of cooling				
Configuration	Bowline	Indian Point	Roseton	Other plants
1	OT	OT	OT	OT
2	CC	CC	CC	OT
3	OT	OT	CC	OT
4	OT	CC	OT	OT
5	CC	OT	OT	OT

^bRuns not done.

3 or 4. This occurs because the major impacts in configuration 5 are due to the once-through operation of Roseton and Indian Point. Thus, at Bowline, the relative importance of impingement vs entrainment is likely greater than at the other two major plants. If the intake f factor for entrainment (f_1) at Bowline were substantially lower than at the other plants, the benefits of installing a cooling tower at Bowline relative to the benefits of installing cooling towers at Roseton or at Indian Point would decrease, but not drastically.

5.8.3.6 Power plant withdrawal rate. Figures 5.8.6 and 5.8.7 illustrate the relationship between total power plant withdrawal rate and percentage reduction. One curve is given for each of the four levels of compensation. All eight curves in the two figures are for the $1.0f_C$ composite f factors. Two general points are evident. First, percentage reduction steadily increases as withdrawal rate increases. One index of the magnitude of this increase is the average of the four percentage-reduction values for configuration 1 divided by the average of the four percentage-reduction values for configuration 2. For Fig. 5.8.6, the value of this ratio is 5.8, while for Fig. 5.8.7, the value is 3.9. The corresponding ratio for total withdrawal rates is 5.8, suggesting that percentage reduction varies about 1:1 with withdrawal rate. It is worth noting that installing cooling towers at Roseton is less effective in decreasing percentage reduction than installing cooling towers at either Bowline or Indian Point. The authors wish to emphasize that this finding is provisional pending further analysis with different freshwater flow regimes and spawning distributions and further analysis of the extent to which failure of the model to impinge the specified number of fish may bias comparisons between power plant configurations.

The second general point is that there is noise in the direct relationship between percentage reduction and withdrawal rate due to spatial effects. The most pronounced deviation is for configuration 5, which has closed-cycle cooling at Bowline. Installing cooling towers at Bowline (configuration 5) reduces the total power plant withdrawal rate less than installing cooling towers at Indian Point (configuration 4). However, the percent reduction values for configuration 5 are actually lower than the values for configuration 4. To a large extent, this result is due to the larger number of striped bass estimated to be impinged at Bowline than at Indian Point (Table 5.5.7).

5.8.3.7 Timing of installation of closed-cycle cooling. The model runs analyzed in Sect. 5.8.3 do not explicitly consider the question of the timing of installation of closed-cycle cooling at Bowline, Roseton, and Indian Point. However, questions of this type have been considered twice before by ORNL.

First, in the IP3 FES, ORNL used its striped bass life cycle model (ref. 5) to assess the difference in the potential benefit and impact of installing a closed-cycle cooling system at Indian Point Unit 3 in 1980, 1982, or 1984 (IP3 FES). ORNL concluded that

Fig. 5.8.6. Percentage reduction in number of yearlings at year 1 vs total power plant withdrawal rate.

Fig. 5.8.7. Percentage reduction in number of adults at year 40 vs total power plant withdrawal rate.

Since the applicant is committed to a cooling tower for Indian Point Unit No. 3 at some date, the sooner it is installed the better from the point of view of reducing the impact on the striped bass population. However, the results of the staff's striped bass life-cycle model suggest that for the levels of impact considered there is not a critical balance point for the Hudson River spawned striped bass population such that, for example, once-through cooling for four years, while undesirable, would be acceptable but that once-through cooling for six or eight years would be unquestionably unacceptable. (IP3 FES)

Second, in the Indian Point Unit 2 FES for a two-year extension (Ref. 11), ORNL assessed the incremental impact on the striped bass population which could result from a two-year extension in the date for cessation of once-through cooling at Indian Point Unit 2. ORNL concluded that

From the point of view of reducing the impact on the striped bass population, the sooner once-through cooling ends at Unit No. 2 the better. However, the striped bass population projections from the staff's life-cycle model indicate to the staff that the incremental long-term impact on the striped bass population due to the requested extension of time is negligible. (IP3 FES)

and

Although the staff certainly does not consider these impingement losses to be trivial, the staff concludes that the incremental long-term impact from these losses is not expected to be large and has essentially no risk of being irreversible. (IP3 FES)

Extrapolating from these results, ORNL concludes the following with respect to the timing of installation of closed-cycle cooling at Bowline, Roseton, and Indian Point: From the point of view of minimizing the impact of power plant exploitation on the striped bass population, the sooner closed-cycle cooling is installed the better. However, there is not a critical balance point or threshold of two, four, or six years which decision makers can fall back on in specifying a date for installation.

5.8.4 Discussion of model results

One additional aspect of these model runs warrants discussion, namely, the relationship between the percentage reduction in yearlings at year 1 and the percentage reduction of adults at age 40. In the LMS model, all compensation acts during the first year of life. The effects of assuming a given level of compensation (as opposed to assuming no compensation) are twofold: primarily, the values of percentage reduction in yearlings at year 1 decrease, and secondarily, the values of percentage reduction in the number of adults at year 40 decrease.

An "impact factor" (ref. 12) can be defined as the ratio of the percentage reduction in adults in year 40, assuming that compensation is operating, divided by the percentage reduction in yearlings in year 1, assuming that compensation is not operating. For example, assuming configuration 2 (Table 5.8.11), Consolidated Edison's best estimate f factors (CEBE), and strong compensation, the impact factor is calculated as $9.48 \div 2.85$, or 3.3. Impact factors which can be calculated from our results range from about 5 (e.g., Table 5.8.9, code number SWC402; no compensation) to less than 2 (e.g., Table 5.8.9, code number SWC121; strong compensation, left limb disabled) to about 0.5 (e.g., Table 5.8.9, code number DLD121; strong compensation, left limb not disabled).

As stated earlier, ORNL feels that the LMS compensatory function is more realistic when the left limb is disabled. Nonetheless, this function does operate only during the first year of life, whereas ORNL feels it is realistic to consider cases in which compensation also operates in adult striped bass. Such additional adult compensation, perhaps mediated by the fishery, would tend to reduce the impact factor values. In addition, even with the left limb of the LMS function disabled, plausible compensation cases, implying impact factors substantially lower than 2 for the same $KX0/KX$ values we have used, could be constructed by varying KX and YS . Other model structures than that used by LMS could, in theory, produce impact factors lower than any implied in our results, although these model structures might be difficult to justify on biological grounds.

As a result of these considerations, ORNL feels that there is a hierarchy of uncertainty in these results. Least uncertain are the estimates of percentage reduction in yearlings in year 1 assuming no compensation, when these estimates are used as indicators of the relative strength of impacts between configurations. Somewhat more uncertain are the absolute estimates of percentage reduction in the number of yearlings at year 1 assuming compensation, although the range of results from no compensation ($KX0/KX = 1$) to strong compensation ($KX0/KX = 0.5$) with the left limb disabled is probably reasonable. Of greatest uncertainty are the absolute estimates of the percentage reduction in the number of adults at year 40. To some extent, this uncertainty is already reflected in the wide range of values obtained (see Table 5.8.9). In addition, ORNL feels that estimates of percentage reduction of adults at year 40 obtained from runs without compensation are not realistic representations of the magnitude of likely population reductions.

A caveat is in order to deemphasize and discourage efforts to play meaningless games with "soft" numbers by treating them as "hard" numbers. The emphasis in discussing the results of the LMS 1-D model is on trends, inequalities, and qualitative and semiquantitative properties of the forecasts. ORNL offers no apology for not presenting a more quantitative assessment, which has a lower level of uncertainty, of the potential impact of the power plants on the Hudson River striped bass population. Our efforts reflect the state of the science and the state of the art of

forecasting the effects of environmental impacts on a large fish population, inhabiting an open system, which is the subject of an intense sport and commercial fishery. ORNL hastens to add that these comments are equally valid for the other models that have been developed and applied to the Hudson River striped bass population.⁴⁻⁷

ORNL emphasizes that the LMS 1-D model is a single-species population model, which appears to simulate the behavior of the striped bass population in a reasonable manner. However, in reality, the Hudson River striped bass population is one component of a complicated fish community that inhabits an even more complicated estuarine and marine ecosystem. Thus the dynamics of the striped bass population undoubtedly depend, to some extent, on interactions between the striped bass and other biotic and abiotic components of the ecosystem. In addition, because striped bass are the subject of an intense sport and commercial fishery and because fishing mortality is probably of importance in regulating the population, the dynamics of this population also depend on social and economic factors that affect fishing effort. None of the available striped bass models include interactions between the striped bass and other biotic and abiotic components of the ecosystem or the social and economic factors that may influence fishing effort.

The justification for the more limited modeling approach adopted is that data on these interactions and social and economic factors are lacking, and even if they were available, an understanding of the cause-effect relationships necessary to include such phenomena in a model is not adequate. The hope is that, by focusing on the population per se, for which there is considerable data, the various models will be sufficiently realistic to a first approximation to serve as part of the basis for making a rational management decision concerning the acceptability or unacceptability of once-through cooling at Rowline, Roseton, and Indian Point and, if unacceptable, the timing of installation of closed-cycle cooling at the three plants.

The LMS 1-D model and the other models available⁴⁻⁷ have certain properties that must be kept in mind when interpreting model results, although ORNL feels that these properties are justified given the present state of the art of forecasting the long-term effects of environmental impacts on a fish population such as the striped bass. A natural steady state has been assumed such that following the removal of a perturbation to the population, such as increased mortality to the young of the year due to entrainment and impingement, the population always returns to the original size it had before the perturbation was applied. ORNL is aware that, in the present application of the model, this assumption of a natural steady state is not consistent with commercial landings and sport catches over the last 40 years or so.^{13,14} The commercial landings and sport catches have both been increasing, and these increases are generally accepted as indicating a real increase in the size of the Atlantic coast striped bass stocks.^{13,14} The fisheries statistics are not adequate to conclude that the Hudson River striped bass population per se has been increasing over the past 40 years. Regardless of past trends, the assumption in the LMS 1-D model of a natural steady state over the next 40 years

is a simplification of what could happen in the future given no power plant impact. This simplification should be kept in mind when interpreting the results.

In this same vein, the approach of making forecasts 40 years into the future merits comment. In any simulation model of this type, the degree of uncertainty in the results steadily increases with each year's projection into the future. Such a situation is an unavoidable consequence of making projections into the future. However, it does not relegate simulation modeling to the status of a meaningless exercise; rather, it requires that, in making a rational management decision, the limitations of simulation modeling and the degree of uncertainty in forecasting 40 years into the future be appreciated.

ORNL presented a lengthy discussion in the IP3 FES (pp. V-162 through V-166) of the phrase "irreversible damage" to describe the possible effects of power-plant-induced mortality on the Hudson River striped bass population. These ideas have been discussed elsewhere by Christensen et al. in more detail and in a more quantitative framework.¹⁵ These ideas are applicable in the present situation.

ORNL's opinion is that the terms irreparable, irreplaceable, irrecoverable, irrevocable, and irretrievable should be considered synonyms. Consider the case where an entrainment impact results in a decrease in the population and in the yield to the fishery, but where subsequently the entrainment impact is eliminated and there is an increase in the population and yield back to prestress levels or to where they would have been in the absence of the impact. In this example, the population would be said to have recovered, although the loss in yield to the fishery during the interim period is irretrievable.

The term irreversible (or permanent), as applied to the effect of a stress such as entrainment or impingement on a population such as the striped bass, has the ecological connotations of (1) biological extinction (i.e., no striped bass of any age class in the Hudson River for all time), (2) fishery extinction (i.e., such a small striped bass population spawning in the Hudson River as to be insignificant in its contribution to the sport and commercial striped bass fishery for all time), or (3) permanent reduction (but above the fishery-extinction level) in population size that continues even after the stress is removed.

ORNL considers biological extinction or fishery extinction due to entrainment and impingement mortality of striped bass eggs, larvae, and juveniles to be only a remote possibility, even with once-through cooling at Bowline, Roseton, and Indian Point for the lifetime of the plants. However, permanent reduction in population size is a possibility. If one component of a biological community is selectively stressed so that population is reduced to low levels for many years, the system of which it is a part will tend to adjust, perhaps in such a way that, even after the stress on this population is removed, the population is unable to

return to the size it would have had in the absence of the impact. The history, present status, and prognosis for several fish populations in Lake Erie is an example of this possibility.¹⁶

To further discuss the possibility of irreversible damage to the Hudson River striped bass population due to the additional stress of entrainment and impingement mortality at the power plants on the Hudson River, it is necessary to distinguish between the following two classes of impact. This distinction was originally discussed by ORNL (IP3 FES, pp. V-164 and V-165) and has recently been emphasized by McFadden.^{7,17}

On the one hand, there are (1) impacts that eliminate spawning and nursery grounds (e.g., dredging or dams) or that in some way render the aquatic environment unsuitable as a habitat for reproduction or existence (e.g., toxic materials or anoxic conditions) and (2) impacts, such as intentional or accidental introduction of new species, that result in changes in the interactions among species within a fish community to the detriment of some of the original species. On the other hand, there are impacts, such as entrainment and impingement, that directly crop a certain fraction of the population (as the fishery does) but that do not directly alter the suitability of the habitat and, if the cropping is not too great, that do not greatly alter the interactions among species within the fish community. The danger of irreversible damage is greater for the first class of impacts than for impacts involving increased cropping of a population.

Although ORNL is concerned that the effects of thermal and chemical discharges from the power plants along the Hudson River could alter the suitability of the habitat, ORNL's primary concern with respect to the striped bass population is the effect of power plant exploitation on top of fishery exploitation. The combined exploitation by the power plants and the fishery, if sufficiently severe and extended over a sufficiently long period of time, could result, both directly and through biological interactions, in substantial changes in the relative population levels of many species. The effect of such changes might be to change the time required for the striped bass population to recover following cessation of major cropping by entrainment and impingement. Alternatively, the combined exploitation could cause or facilitate a shift to a different and stable set of relative population levels in the fish community that would prevent eventual recovery of the striped bass population to the level it would have had in the absence of the impact. The present level of understanding of species interactions in complex ecosystems is not sophisticated enough to permit quantitative statements to be made about the likelihood of such "permanent" changes occurring as a result of 30 or 40 years of a specified level of exploitation.

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5.9 Hudson River Striped Bass Stock

One of the primary issues in controversy during the past several years related to assessing the potential impact of power plant operation on the Hudson River striped bass stock has been the relationship of this stock to other striped bass stocks along the Atlantic coast. The objective of this section is to review the state of knowledge concerning (1) the zone of influence of the Hudson River striped bass stock and (2) the relative contribution of this stock to the Atlantic coastal striped bass population.

5.9.1 Zone of influence

Recapture locations of sexually mature striped bass tagged in the Hudson River during the spawning season (approximately April through June) provide an indication of the zone of influence of the Hudson River striped bass population. This methodology is predicated on the assumption that the location of a sexually mature striped bass during the spawning season indicates the stock to which it belongs, the possibilities being Hudson River stock, Delaware River stock, various Chesapeake stocks, and Roanoke River stock.

ORNL provided a summary of reported recoveries of striped bass tagged in the Hudson River north of Yonkers, New York, during the pre-spawning and spawning period (March through June) for the years 1969-1974 (IP3 FES, pp. V-166-V-169). For 21 out of the 35 recaptures considered, data were not available on sex, age, or size. For the remaining 14 recaptures, all of which had been tagged by Texas Instruments, only 5 had been tagged in April. The other nine were tagged in March, which is considered part of the prespawning period; thus there is a greater risk of error in assigning these fish to the Hudson stock, because striped bass of Chesapeake origin have been shown to overwinter in the lower Hudson River. ORNL reached the following conclusion (IP3 FES, pp. V-166, V-169).

The pattern of recapture locations indicates that Hudson striped bass contribute to the fisheries in the Hudson River itself, Long Island Sound, the New York Bight, and New England (as far north as Boston, Mass.). The staff defines the New York Bight as the coastal zone from Barnegat Inlet, New Jersey, to Moriches Inlet on the south shore of Long Island.

These recapture locations probably delineate the northern boundary of the zone of influence of the Hudson River striped bass population more accurately than they delineate the southern boundary. Ninety-seven percent of the fish recaptured (i.e., 34 out of 35) were recaptured during mid-March through October, which includes the period when the coastal migratory stock is known to be in the northern part of its range. Only one fish was recaptured from November through mid-March, which includes the period when the coastal migratory stock

is known to be in the southern part of its range. Only one of the 35 striped bass recaptured was recaptured along the New Jersey coast or south, and that one was recaptured off Monmouth County, which is the northernmost coastal county in New Jersey. The above analysis has caused the staff to shift its emphasis in defining the zone of influence of the Hudson River striped bass population from the mid-Atlantic region (Appendix F, IP3, DES) to the northern part of the mid-Atlantic region and the New England region.

The staff wishes to emphasize that tag-recapture data of the quality and quantity currently available are only of value in generally indicating where along the Atlantic Coast the Hudson River striped bass population is contributing to the fishery. These data do not provide a basis for estimating the percentage contribution of the Hudson stock to the mid-Atlantic or New England fisheries or even to the striped bass fishery in . . . the Inner Zone. [The Inner Zone is defined as] the Hudson River, the western half of Long Island Sound (both the north and south shores west of Bridgeport, Connecticut, and Port Jefferson, Long Island, New York), and the New York Bight (Barnegat Inlet to Moriches Inlet).

Texas Instruments has recently completed a comparable analysis (ref. 1) but including more recent recaptures. The highlights of their analysis, which considers the information in Table 5.9.1 and Fig. 5.9.1, are quoted below (ref. 1, Appendix A, pp. A-4-A-11).

TI's data on striped bass migration from wintering-spawning areas in the Hudson River to areas outside the river indicate that some large individuals make extensive northeast movements into New England waters and that larger fish migrate farther. Clark's (1968) Hudson-Atlantic contingent is confirmed by fish tagged in the spring on known spawning grounds which were recaptured as far away as Boston Harbor, and seems to be composed primarily of very large striped bass (> 80 cm). Large striped bass reportedly make extensive oceanic migrations (Chapoton and Sykes, 1961; Schaefer, 1968) as did those tagged in the Hudson River. Fish moving < 200 km (e.g., those taken in western Long Island Sound [Clark's Hudson-West Sound contingent]) tend to be smaller (50-80 cm). Individuals < 40 cm were not recovered outside the Hudson estuary, indicating the relatively nonmigratory status of smaller striped bass as reported for other estuarine systems (Vladykov and Wallace, 1938, 1952; Merriman, 1941; Raney, 1952, 1957; Mansueti, 1961; Massman and Pacheco, 1961; Nichols and Miller, 1967).

A recurring question of fundamental importance in a study such as this is the origin of the tagged fish: are they of the Hudson River stock? There is evidence that Hudson River fish are genetically distinct from those found in more

Table 5.9.1. Release and recovery data for recaptured striped bass tagged in the Hudson River, 1972-1974

Release Data				Recovery Data				
Date	Location (River KM)	Total Length (mm)	Age	Date	Location	Days at Large	Approximate Distance (km) from Tagging Site	Recapture Gear
1972								
Dec 28	54	555	---	5/1/73	Long Island Sound, Rye, NY	123	104	SF
	54	605	---	5/25/73	Long Island Sound, Greenwich, CT	147	112	SF
1973								
Jan 3	54	567	---	4/23/73	Hudson River Kilometer 54	110	<1	CF
	54	588	---	3/30/73	Long Island Sound, Little Neck Bay, NY	86	80	SF
Mar 9	53	645	VI	4/23/73	Hudson River Kilometer 54	45	1	CF
	53	570	V	4/27/73	Hudson River Kilometer 62	49	9	PS
	53	670	V	7/21/73	Long Island Sound, Mamaroneck, NY	34	95	SF
13	51	610	V	5/1/73	Hudson River Kilometer 62	49	11	PS
	51	650	V	6/20/73	Long Island Sound, Glen Cove, NY	99	104	SF
	51	650	V	7/27/73	Long Island Sound, Stamford, CT	36	112	SF
14	54	552	---	3/14/73	Hudson River Kilometer 54	1	<1	SF
15	53	870	VIII	7/5/73	Nantucket Sound, Nantucket MA	112	400	CF
26	54	575	---	6/7/73	Great South Bay, R. Moses Bridge, NY	73	136	CF
	54	660	---	9/5/74	Long Island Sound, Stamford, CT	528	112	SF

Table 5.9.1 (continued)

Date	Location (River KM)	Total Length (mm)	Age	Date	Location	Days at Large	Approximate Distance (KM) from Tagging Site	Recapture Gear
Apr 3	53	492	IV	4/13/73	Hudson River Kilometer 50	10	3	CF
19	96	903	VII	10/12/73	Block Island Sound, Montauk Pt., NY	174	296	SF
20	94	975	IX	6/19/73	Buzzards Bay, New Bedford, MA	60	389	SF
	91	1040	VIII	7/15/74	Boston Harbor Boston, MA	451	512	SF
20	94	745	VII	9/17/73	Lower NY Bay Rockaway Pt., NY	145	128	SF
Nov 12 1974	62	645	VI	6/10/74	Stockport Creek, tributary to Hudson River at Kilometer 192	179	144	SF
Apr 23	87	908	IX	9/2/74	Hudson River Kilometer 53	9	14	SF
24	22	120	I	8/1/74	Hudson River Kilometer 46	99	24	SF
30	88	808	---	6/15/75	Gravesend Bay Coney Island, NY	411	105	SF
May 16	67	1035	X	6/27/74	Cape Cod Bay Orleans, MA	42	416	SF
Sep 18	46	145	---	10/29/74	Hudson River Kilometer 46	41	<1	PS
20	86	144	---	5/29/75	Hudson River Kilometer 86	251	<1	PS
Oct 9	56	238	---	6/23/75 [†]	Hudson River Kilometer 19	258	37	SF
25	67	165	---	11/13/74	Hudson River Kilometer 67	19	<1	PS
Nov 4	64	174	---	11/15/74	Hudson River Kilometer 64	11	<1	PS

Table 5.9.1 (continued)

Date	Location (River Kil)	Total Length (mm)	Age	Date	Location	Days at Large	Approximate Distance (KM) from Tagging Site	Recapture Gear
1975								
Apr 8	54	572	---	8/1/75	Housatonic River, Stratford, CT	115	156	SF
15	56	578	---	4/29/75	Hudson River Kilometer 43	14	13	CF
16	56	607	VI	4/17/75	Hudson River Kilometer 56	1	<1	PS
16	56	591	VI	8/21/75	Atlantic Beach Long Island, NY	127	98	SF
17	56	567	VII	4/18/75	Hudson River Kilometer 56	1	<1	PS
17	61	586	V	4/18/75	Hudson River Kilometer 61	1	<1	PS
17	61	661	VI	4/18/75	Hudson River Kilometer 61	1	<1	PS
17	56	590	VI	4/29/75 [†]	Hudson River Kilometer 46	12	10	SF
23	56	592	---	4/24/75	Hudson River Kilometer 56	1	<1	PS
29	56	624	VII	4/30/75	Hudson River Kilometer 43	1	13	CF
29	61	568	---	4/30/75	Hudson River Kilometer 43	1	18	CF
30	56	660	---	6/2/75	Long Island Sound, Mamaroneck, NY	33	99	SF
30	56	847	IX	6/22/75	Fallmouth Heights, MA	53	367	SF
May 1	61	846	X	5/2/75	Hudson River Kilometer 61	1	<1	PS
7	53	473	---	6/2/75	Block Island Sound, Shagwong Point, NY	26	248	CF
14	67	535	---	6/10/75	Verrazano Bridge Lower Bay, NY	27	78	SF
23	66	944	---	6/4/75	Cuttyhunk, MA	12	349	SF
27	64	174	---	6/10/75	Hudson River Kilometer 64	14	<1	PS
Jun 10	64	192	---	6/23/75	Hudson River Kilometer 64	13	<1	PS

* SF Sport fishing
CF Commercial fishing
PS Project sampling

[†] Date represents postmark date; no more accurate recapture data are available.

From Texas Instruments, Inc., *Report on Relative Contribution of Hudson River Striped Bass to the Atlantic Coastal Fishery*, prepared for Consolidated Edison Company of New York, Inc., December 1976.

Fig. 5.9.1. Returns of striped bass to the area outside the Hudson River and its tributaries. From Texas Instruments, Inc., *Report on Relative Contribution of Hudson River Striped Bass to the Atlantic Coastal Fishery*, prepared for Consolidated Edison Company of New York, Inc., December 1976.

southerly waters (Raney and deSylva, 1953; TI, 1975b). It has also been suggested (Raney and deSylva, 1953; Raney et al 1954) that striped bass of other stocks may overwinter in the Hudson River. Hence, fish tagged during the winter (January-March) are of questionable origin. TI assumes that those fish tagged in the spring (April-June) on known spawning grounds (Rathjen and Miller, 1957; TI, 1975a) most likely are of Hudson River stock. In April and May, 13 such fish tagged at river KM 53-96 were recovered outside the Hudson; seven of these were recovered > 200 km from the point of release and as far away as Boston Harbor. The proportion of the available population making large-scale movements cannot be determined based solely on tagging data; however, the larger, older individuals that engage in extensive coastal migrations are not likely to represent a very large portion of the Hudson River striped bass population. Smaller individuals (40-80 cm) appear to restrict their movements outside the Hudson primarily to western Long Island Sound and the southwestern shore of Long Island. Fish < 40 cm in total length were not recaptured outside the Hudson River.

A number of rivers along the Atlantic Coast produce striped bass, and most tagging studies have indicated the same general migratory patterns for all stocks that are well studied, i.e., a northward migration of older individuals along the coast in late spring and southward return migration in late fall (Merriman, 1941; Vladykov and Wallace, 1952; Raney et al, 1954; Massman and Pacheco, 1961; Chapoton and Sykes, 1961; Nichols and Miller, 1967). TI's study would seem to indicate a similar pattern of migration by Hudson River stock. Thus, the Hudson River may be expected to contribute some fish to fisheries as far away as Massachusetts.

REFERENCES FOR THE EXCERPT

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The ORNL and TI analyses both support the position that the Hudson River stock does contribute to the striped bass population along the New England coast, at least as far north as Boston, Massachusetts. In addition, given the limited number of recaptures with which to define a zone of influence, the possibility that the zone of influence extends to New Hampshire and Maine cannot be ruled out.

The southern boundary of the zone of influence, based on location of recaptures, is still vague, in spite of the additional recaptures reported by Texas Instruments. There is only a single recovery anywhere during the entire half-year period from October through March of a fish, large enough to be considered sexually mature, tagged in the Hudson River during April through June (Table 5.9.1; release data of April 19, 1973). As ORNL pointed out in the IP3 FES, the period October through March includes the time when the coastal migratory stock is known to be in the southern part of its range.

5.9.2 Relative contribution of Hudson River stock to the Atlantic coastal population

Analysis of recapture data, as in Sect. 5.9.1, provides estimates of northern and southern limits for the zone of influence of the Hudson River stock. A second and more crucial issue is the relative contribution of the Hudson stock within this zone of influence.

ORNL's position on this issue at the time of the IP3 FES is summarized as follows (IP3 FES, pp. V-169, V-176, V-177):

The Hudson River stock is the major source of striped bass caught in the Hudson River, the western half of Long Island Sound (both the north and south shores west of Bridgeport, Connecticut, and Port Jefferson, Long Island, New York), and the New York Bight (Barnegat Inlet to Moriches Inlet). The staff refers to this zone as the Inner Zone of influence of the Hudson River spawned striped bass population. By "majority" the staff means more than 50% of the sport and commercial landings, but less than 100% since adult striped bass tagged in the Chesapeake during the pre-spawning and spawning season have been recaptured in this region....¹⁴⁶

The staff defines an Outer Zone of influence of the Hudson River spawned striped bass population as extending from Maine to Cape May County, New Jersey, inclusive, less the Inner Zone previously defined. The staff's present best judgment is that the percentage contribution of the Hudson River striped bass population to the Outer Zone cannot be accurately estimated on the basis of data presently available. Estimates of the contribution to the mid-Atlantic ranging from "no more than 10%" (IP3, ER, App. HH) to "a minimum of approximately 80%" (IP3, DES, p. V-85 and App. F) have been presented.

All parties are in agreement that at present, with the Delaware River so heavily polluted, spawning of striped bass there is insignificant, although striped bass do use the Chesapeake and Delaware Canal and Elk River areas to spawn. Thus, the two primary sources for the mid-Atlantic and New England stock are the Hudson River and Chesapeake Bay.

The proportion contributed by each source undoubtedly varies somewhat from year to year, from the sport fishery to the commercial fishery, and from place to place (i.e., Cape Cod to the southeast shore of Long Island to the southern coast of New Jersey).

REFERENCE FOR THE EXCERPT

146. Massmann, W. H., and A. L. Pacheco, "Movement of Striped Bass Tagged in Virginia Waters of Chesapeake Bay," *Chesapeake Sci.* 2(1-2): 37-44 (1961).

At the time of the IP3 FES, Texas Instruments was just undertaking a study to obtain data to help resolve the relative contribution question. At that time, ORNL commented (IP3 FES, pp. V-177, V-178):

One aspect of the applicant's research program is directed at estimating the contribution of the Hudson River striped bass population to the Mid-Atlantic and New England fisheries. In the staff's opinion the research program has the potential for narrowing the present range of uncertainty by the end of 1976, if not sooner. The applicant's approach will be to develop a character block for the Hudson stock and for the Chesapeake stock (and perhaps for substocks within the Chesapeake, i.e., Potomac, Elk River, James River, etc.). This character block will consist of three primary strata: (1) a character index combining the number of rays (bones) in the anal, dorsal, and pectoral fins of striped bass; (2) a critical analysis of the vertical relief profile on the surface of striped bass scales from the focus (origin) to the second annulus or growth ring; and (3) electrophoretic analysis of serum proteins.

Preliminary data are available only for the first stratum. These data indicate a modal number of 54 rays, with 58% of the fish in the range of 53 to 55 rays, for Hudson River striped bass and a modal number of 57 rays, with 72% of the fish in the range of 56 to 58 rays, for Chesapeake striped bass. In other words, there are two somewhat distinct but overlapping frequency distributions. The staff anticipates a similar situation with the other two strata. The final task will be to obtain data for all three strata from samples having unknown proportions of fish from the Hudson and Chesapeake and then to use discriminant analysis or equivalent techniques to obtain a point estimate and measure of variability of the proportion of fish of Hudson origin in the mixed sample.

The staff's position is that this aspect of the applicant's research program probably will narrow the present range of uncertainty by the end of 1976. However, the staff expects

that there will be considerable overlap among the character blocks of the various stocks and that the degree of uncertainty will still be appreciable (e.g., ± 20 to 30%).¹⁴² Furthermore, the staff expects the proportion of fish of Hudson River origin in a mixed sample to vary from place to place for a given year (e.g., Cape Cod to Montauk Point to the southern New Jersey coast) and from year to year at a given place.

REFERENCE FOR THE EXCERPT

142. Testimony of C. P. Goodyear, "Staff Responses to Interrogatories for Dr. C. P. Goodyear re Staff Comments on Applicant's Research Program. Set II," Indian Point Unit No. 2 ASLB Hearings, Docket No. 50-247, April 20, 1973.

Texas Instruments has just released a report on the results of this study.¹ The Summary and Conclusions from this report are quoted below.

SUMMARY AND CONCLUSIONS

Texas Instruments Incorporated (TI) conducted a study to identify the origin of striped bass collected in the Atlantic coastal fishery, thus providing a basis for estimating the relative contribution of the Hudson River stock to that fishery. TI applied a quadratic discriminant routine on values of five meristic and morphometric characters obtained from Hudson, Chesapeake and Roanoke spawning stock specimens to determine functions which best separated the stocks. Correct classification of 76.8, 67.7, and 85.9% for the Hudson, Chesapeake, and Roanoke spawning stocks, respectively, were obtained, resulting in an overall correct classification of 74.4%. Most of the misclassifications occurred between the Hudson and Chesapeake stocks, as indicated by overlaps of 24.06, 4.44, and 10.94% obtained for the Hudson-Chesapeake, Hudson-Roanoke, and Chesapeake-Roanoke spawning-stock pairs respectively. The character set was the most generally applicable set of characters that distinguished among fish spawning in the Hudson, Chesapeake, and Roanoke estuaries as indicated by a cross-validation procedure.

Assessment of the relative contribution of various stocks of striped bass to the Atlantic coastal fishery was made on collections of striped bass from geographical and temporal strata. The geographical stratification consisted of ten strata from southern Maine to Cape Hatteras, North Carolina. Temporally, the year was divided into six two-month periods. Mean estimates of contribution were obtained by averaging the estimates within the strata. Since the assessment of contribution to the coastal fishery required that the individuals were actually part of

the fishery, collections of striped bass of sublegal size and those overwintering in the Hudson River were analyzed separately.

Oceanic samples were classified by the discriminant functions, and mean estimates of 23.0% Hudson, 66.0% Chesapeake, and 11.0% Roanoke stocks were obtained within the Atlantic coastal fishery over the entire year. The relative contribution to the fishery of the Hudson stock exceeded 30% only in Rhode Island, western Long Island Sound and the New York Bight during certain periods. Approximately 52% of the specimens collected in the 1975 oceanic sampling program were from the 1970 year class and 77% of these were classified as Chesapeake fish, overshadowing the Hudson and Roanoke classification percentages.

Biochemical data provided evidence that either (1) an influx of southern migrants or (2) a unique late-breeding segment of Hudson stock occurred in the Hudson River after 23 May 1975. Estimates of the relative contribution of Hudson River stock to the 1975 oceanic collections increased or decreased depending on which hypothesis was accepted. Differences up to 16 percentage points between the estimates obtained from the two hypotheses occurred during the summer months; however, the yearly estimates varied < 5 percentage points.

The relative contribution of the Hudson stock exceeded that of the Chesapeake stock for sublegal-sized striped bass (fork length < 406.5 mm) captured in western Long Island Sound and the New York Bight and all striped bass captured overwintering in the Hudson River. In collections from western Long Island Sound and the New York Bight, the Hudson's contribution of sublegal fish was $\geq 80\%$; for Hudson River collections of overwintering fish a contribution of 76.3% Hudson stock was estimated.

Estimates of relative contribution of Hudson stock to commercial landings during the 2-month periods in 1975 ranged from 10.4 to 28.3%, with a 20.4% weighted average contribution for the entire year. The year exhibited 68.1% Chesapeake and 11.4% Roanoke stock contributions; these were similar to the yearly estimates of unweighted mean relative contributions of 23.0% Hudson, 66.0% Chesapeake, and 11.0% Roanoke stocks. Based on the average of 1973 and 1974 weighting factors for commercial landings, the mid-Atlantic region yielded approximately three times more poundage than did either the New England region, coastal Chesapeake region or coastal South Atlantic region north of Cape Hatteras, North Carolina.

Estimates of the relative contribution of the Hudson River stock to the "inner" and "outer" zones defined by the United States Nuclear Regulatory Commission (USNRC) in its environmental statement were 31.7 and 19.2% respectively. This was substantially lower for the "inner" zone than the estimated 90% contribution currently used by USNRC. For the "outer" zone, however, the estimate is intermediate between the USNRC values of 10 and 50% contribution.

To date, this study concludes that

The Chesapeake stock is the major contributor to the Atlantic coastal striped bass fishery from southern Maine to Cape Hatteras, North Carolina.

The Chesapeake stock is also the major contributor of legal-sized fish in the near vicinity of the Hudson River-western Long Island Sound and the New York Bight.

Sublegal striped bass collected in the vicinity of western Long Island Sound and the New York Bight are predominately of Hudson origin.

Striped bass overwintering in the Hudson River are predominately of Hudson origin.

Based on expected correct classification of 76.8, 67.7, and 85.9% of the Hudson, Chesapeake, and Roanoke specimens in the oceanic collections, the relative contribution of Hudson River striped bass to the Atlantic coastal fishery is approximately 20%.

Since this estimate is within the range where bias becomes important, techniques to reduce misclassification and/or bias in the estimates of relative contribution need to be investigated.

In written testimony presented at hearings in December 1976,² Texas Instruments immediately modified some of the above estimates as indicated in Table 5.9.2. The justification offered for these modified estimates was "that additional statistical techniques have been utilized since the drafting of the enclosed report. These techniques were instituted to reduce the bias in the estimates of stock contribution."³

The issue of the relative contribution of the Hudson River stock to the Atlantic coastal striped bass population figures prominently in reaching a reasoned decision, based on a cost-benefit and risk-benefit analysis, on the need for closed-cycle cooling at Bowline, Indian Point, and Roseton. Thus, given the importance of this issue, the only recent

Table 5.9.2. Estimates of percentages of contribution from three spawning river systems to the Atlantic striped bass fishery

(Estimates not in parentheses are from ref. 1; estimates in parentheses are from ref. 2)

	Hudson	Chesapeake	Roanoke
Coastal fishery	7 (23)	90 (66)	3 (11)
NRC inner zone	15 (32)	84 (63)	1 (5)
NRC outer zone	40 (19)	96 (68)	4 (13)

References:

1. Testimony of Dr. K. Perry Campbell, Dr. John P. Lawler, Dr. Kenneth L. Marcellus, Dr. Mallory S. May, and Dr. James T. McFadden before the Atomic Safety and Licensing Board for Facility License Amendment for Extension of Operation with Once-through Cooling for Indian Point Unit No. 2, Consolidated Edison Company of New York, Inc., Docket No. 50-247, December 7, 1976.

2. Texas Instruments, Inc., *Report on Relative Contribution of Hudson River Striped Bass to the Atlantic Coastal Fishery*, prepared for Consolidated Edison Company of New York, Inc., December 1976.

availability of the TI report, and the obvious sensitivity of the estimates to the method of analysis, the following conclusion is appropriate at this time. The Texas Instruments study does appear to have narrowed the range of uncertainty from the previous range of "no more than 10%" to "a minimum of approximately 80%." In addition, the new estimates are closer to 10% than to 80%. However, in the absence of a detailed report from TI documenting the "additional statistical techniques . . . to reduce the bias" and in the absence of an independent analysis of the raw data, it seems prudent to use the estimates with and without parentheses in Table 5.9.2 as a "working range" for the relative contribution of the Hudson stock to the Atlantic coastal striped bass population.

REFERENCES FOR SECTION 5.9

1. Texas Instruments, Inc., *Report on Relative Contribution of Hudson River Striped Bass to the Atlantic Coastal Fishery*, prepared for Consolidated Edison Company of New York, Inc., December 1976.
2. Testimony of Dr. K. Perry Campbell, Dr. John P. Lawler, Dr. Kenneth L. Marcellus, Dr. Mallory S. May, and Dr. James T. McFadden before the Atomic Safety and Licensing Board, U.S. Nuclear Regulatory Commission, for Facility License Amendment for Extension of Operation with Once-through Cooling for Indian Point Unit No. 2, Consolidated Edison Company of New York, Docket No. 50-247, December 7, 1976.
3. J. T. Major, Texas Instruments, Inc., letter to L. Rodriguez, Consolidated Edison Company of New York, Inc., dated December 2, 1976.

APPENDICES A THROUGH D ARE INCLUDED IN VOLUME 1

Appendix E

MONTHLY COLLECTION RATES FOR ALEWIFE, BAY ANCHOVY, BLUEBACK HERRING, ATLANTIC TOMCOD, AND WHITE PERCH, 1972-1975

Monthly collection rates for alewife, bay anchovy, blueback herring, Atlantic tomcod, and white perch¹ are given in Tables E-1 — E-5. These tables cover the period June 1972-December 1975, and they include estimates of the monthly collection rate for all months for which Oak Ridge National Laboratory was able to find the necessary data. Where there are conflicting estimates, an appropriate footnote has been included, and in some cases two estimates are presented. These conflicts should be resolved by the appropriate utility as soon as possible. Also, Central Hudson (Roseton and Danskammer), Orange and Rockland (Bowline and Lovett), and Niagara Mohawk (Albany) and their contractor (Lawler, Matusky, and Skelly Engineers) have data that have not been made available in reports but that would permit the filling in of numerous blanks presently existing in the table. The value of this type of multiyear and multiplant tabulation of monthly collection rates by species is illustrated and discussed for striped bass in Sect. 5.5.

Table E-1. Summary of available estimates of monthly collection rates for alewife for the power plants along the Hudson River for the years 1972 through 1975^a

Year	Month	Power plant							Albany	
		Bowline	Lovett	Indian Point			Roseton	Danskammer		
				Unit 1	Unit 2	Unit 3		Units 1 and 2		Units 3 and 4
1972	June			1	1					
	July			0	-					
	August			20	-					
	September			16	0					
	October			5	0					
	November			0	-					
	December			0	-					
1973	January			0	0					
	February			-	0					
	March			-	0					
	April			-	0					
	May			0	0					
	June			1	1					
	July			-	6					
	August			0	7					
	September			0	1					
	October			-	1					
	November			4	4					
	December			4	1					
1974	January			0	0	-	0.00	0.00	0.00	-
	February			0	0	-	-	0.00	0.00	-
	March			0	0	0	0.00	0.00	0.00	-
	April			0	0	4	0.29	116.	3.99	14.3
	May			7	4	8	3.99 ^b	222.	20.9	55.3
	June			4	3	12	1.22 ^b	78.9 ^b	5.97	7.98
	July			6	5	3	7.40 ^b	143.	27.3 ^b	45.5
	August			4	4	2	11.9 ^b	144.	105.	294.

Table E-1 (continued)

Year	Month	Power plant								Albany
		Bowline	Lovett	Indian Point			Roseton	Danskammer		
				Unit 1	Unit 2	Unit 3		Units 1 and 2	Units 3 and 4	
1975	September			5	3	0	4.62 ^b	192.	64.6	148.
	October	51.0	39.3	27	13	12	2.30 ^b	522.	148.	94.5
	November	114.0	11.5	7	4	-	2.17 ^b	76.3	12.7	0.36
	December	7.51	0.00	7	0	-	0.00	1.32	0.32	0.00
	January	2.64	2.64	1	0		0.00	0.95	0.00	0.00
	February	2.64	5.28	8	1		0.00	0.00	0.00	0.00
	March	2.64	2.64	1	0		0.16	5.44	0.00	0.00
	April	13.2	2.64	1	0					
	May	5.28	7.93	2	1					
	June	5.28	5.28	3	3					
	July	50.2	10.6	3	23					
	August	2.64	23.8	2	2					
September	2.64	10.6	-	2						
October	2.64	5.28	-	4						
November	2.64	81.9	-	9						
December	13.2	5.28	-	1						

^aUnits for collection rate are number of fish per million cubic meters of power-plant intake flow. Y (number/ 10^6 m³) = 264.17 (gal/m³) x number/ 10^6 gal). Estimates of collection rate for alewife and blueback herring combined are given in Table E-3 for blueback herring for the period January 1973 through September 1974. These combined estimates are based on data reported in ref. 1.

^bTwo conflicting estimates of power-plant intake flow were provided; the estimate that appeared most likely to be correct was used.

Table E-2. Summary of available estimates of monthly collection rates for bay anchovy for the power plants along the Hudson River for the years 1972 through 1975^a

Year	Month	Power plant								Albany
		Howline	Lovett	Indian Point			Roseton	Danskammer		
				Unit 1	Unit 2	Unit 3		Units 1 and 2	Units 3 and 4	
1972	June			0	0					
	July			0	-					
	August			160	-					
	September			181	2					
	October			43	3					
	November			1	-					
	December			1	-					
1973	January			0	0					
	February			-	0					
	March			-	0					
	April			-	0					
	May			0	0					
	June			0	0					
	July			-	4					
	August			0	103					
	September			0	59					
	October			-	8					
	November			3	1					
	December			0	0					
1974	January			0	0	-	0.00	0.00	0.00	-
	February			0	0	-	-	0.00	0.00	-
	March			0	0	0	0.00	0.00	0.00	-
	April			0	0	0	0.00	0.00	0.00	0.0
	May			-	2	0	0.37 ^b	0.00	0.37	0.0
	June			39	60	37	0.66 ^b	1.20 ^b	0.00	0.0
	July			119	230	211	0.95 ^b	5.42	2.30 ^b	0.0
	August			98	198	6	51.5 ^b	18.7	34.4	0.0

Table E-2 (continued)

Year	Month	Power plant								Albany
		Bowline	Lovett	Indian Point			Roseton	Danskammer		
				Unit 1	Unit 2	Unit 3		Units 1 and 2	Units 3 and 4	
1975	September			63	162	1	11.3 ^b	5.15	9.83	0.0
	October	5.66	4.61	41	20	2	0.92 ^b	0.92	3.96	0.0
	November	0.92	0.00	0	0	-	0.0	0.00	0.00	0.0
	December	1.32	0.18	0	0	-	0.0	0.00	0.00	0.0
	January	c	c	0	0		0.00	0.00	0.00	0.0
	February	c	c	0	0		0.00	0.00	0.00	0.0
	March	c	c	0	0		0.00	0.00	0.00	0.0
	April	c	c	0	0					
	May	c	c	0	0					
	June	5.28	2.64	7	14					
	July	31.7	23.8	38	244					
	August	2.64	13.2	33	546					
	September	2.64	7.93	-	258					
	October	c	2.64	-	150					
	November	c	c	-	0					
	December	c	c	-	0					

^aUnits for collection rate are number of fish per million cubic meters of power-plant intake flow. Y (number/ 10^6 m³) = 264.17 (gal/m³) x (number/ 10^6 gal).

^bTwo conflicting estimates of power-plant intake flow were provided; the estimate that appeared most likely to be correct was used.

^cLess than 2.64 fish/ 10^6 m³.

Table E-3. Summary of available estimates of monthly collection rates for blueback herring for the power plants along the Hudson River for the years 1972 through 1975^a

Year	Month	Power plant								Albany
		Bowline	Lowett	Indian Point			Rcseton	Danskammer		
				Unit 1	Unit 2	Unit 3		Units 1 and 2	Units 3 and 4	
1972	June			0	0					
	July			0	-					
	August			0	-					
	September			1	0					
	October			35	1					
	November			7	-					
	December			0	-					
1973	January	0.66	0.17	0	0			0.00	0.61	
	February	0.83	0.41	-	0			0.00	0.00	
	March	0.00	0.88	-	0			0.00	0.00	
	April	1.10	2.99	-	0			103.	1.86	
	May	2.49	5.13	0	0			155.	14.0	
	June	2.17	3.54	0	0			99.2	15.2	
	July	160.	32.4	-	0			134.	173.	
	August	124.	74.5	0	0			1571.	256.	
	September	8.39	12.2	0	0			3586.	501.	
	October	16.2	3.26	-	1			2890.	503.	
	November	250.	217.	52	30			1073.	302.	
	December	88.6	78.7	18	23			2.69	1.88	
1974	January	198.	9.94	0	0	-	0.40	0.0	0.00	-
	February	1.16	18.4	0	1	-	-	0.0	0.00	-
	March	1.16	-	0	0	0	0.00	0.0	0.00	-
	April	-	36.4	1	6	0	7.26	71.7	5.79	10.1
	May	12.9	25.0	4	17	0	11.2 ^b	15.4	9.01	255.
	June	6.39	17.7	9	7	20	11.5 ^b	63.3 ^b	13.0	143.
	July	4.74	6.91	1	1	1	0.58 ^b	23.4	2.30 ^b	23.2
	August	9.57	6.80	2	2	0	17.4 ^b	10.9	41.2	23.6

Table E-3 (continued)

Year	Month	Power plant								Albany
		Bowline	Lovett	Indian Point			Roseton	Danskammer		
				Unit 1	Unit 2	Unit 3		Units 1 and 2	Units 3 and 4	
1975	September	16.1	12.1	3	3	0	14.6 ^b	63.7	16.4	785.
	October	228.	431.	159	72	2	17.1 ^b	90.4	104.	497.
	November	127.	116.	397	180	-	2.13 ^b	127.	29.2	47.4
	December	3.90	1.29	1	0	-	0.0	0.66	0.00	.12
	January	5.28	2.64	1	0		0.0	0.00	0.00	0.00
	February	7.93	2.64	4	0		0.00	0.00	0.00	0.00
	March	2.64	2.64	1	0		0.16	0.00	0.00	0.00
	April	95.1	34.3	9	3					
	May	5.28	5.28	6	3					
	June	2.64	5.28	3	1					
	July	7.93	2.64	5	13					
	August	c	c	1	14					
	September	c	2.64	-	7					
	October	7.93	106.	-	928					
November	232.	87.2	-	1146						
December	34.3	7.93	-	126						

^aUnits for collection rate are numbers of fish per million cubic meters of power-plant intake flow. $Y \text{ (number}/10^6 \text{ m}^3) = 264.17 \text{ (gal}/\text{m}^3) \times \text{(number}/10^6 \text{ gal)}$. Estimates of collection rate for each of the power plants except Indian Point during the period January 1973 through September 1974 are for blueback herring and alewife combined (i.e., *Alosa* spp., except for American shad). These combined estimates are based on data reported in ref. 1. Collection rates for blueback herring and alewife combined for other months and years may be obtained by adding the rate for blueback herring in this table to the rate for alewife in Table E-1.

^bTwo conflicting estimates of power-plant intake flow were provided; the estimate that appeared most likely to be correct was used.

^cLess than 2.64 fish/10⁶ m³.

Table E-4. Summary of available estimates of monthly collection rates for tomcod for the power plants along the Hudson River for the years 1972 through 1975^a

Year	Month	Bowline	Lovett	Power plant					Albany	
				Indian Point			Roseton	Danskammer		
				Unit 1	Unit 2	Unit 3		Units 1 and 2		Units 3 and 4
1972	June			5	236					
	July			5	-					
	August			138	-					
	September			932	115					
	October			162	276					
	November			4	-					
	December			6	-					
1973	January	135.	1052.	6	687			8671.	21590.	
	February	38.9	527.	-	86			4302.	5795.	
	March	1.20	95.5	-	8			4235.	601.	
	April	3.96	9.19	-	22			40.2	5.59	
	May	7.97	0.73	2	11			34.2	10.8	
	June	3.53	2.48	2	195			2.18	2.05	
	July	7.27	5.19	-	190			5.82	6.29	
	August	16.5	49.2	0	42			2.10	2.11	
	September	0.22	0.00	0	9			1.09	0.44	
	October	0.00	0.47	-	0			12.1	0.57	
	November	0.19	0.00	1	0			3.23	0.00	
	December	0.26	0.00	92	5			40.3	314.	
1974	January	2.10	244.	24	2	-	34.9	706.	3637.(3509.)	-
	February	5.81	29.2	1	1	-	-	5141.(5101.)	411.(428.)	-
	March	1.15	-	0	0	0	0.00	41.3	48.8(52.4)	-
	April	-	0.0	0	0	0	0.00	19.3(16.5)	0.45	0.06
	May	0.35	0.0	23	141	0	12.9 ^b	0.95	0.00	0.13
	June	64.2	109.	590	959	1280	24.6 ^b	12.0 ^b	3.51	9.95
	July	63.0	93.7	107	669	846	4.15 ^b	24.8	0.90 ^b	5.26
	August	2.51	63.4	223	481	102	7.66 ^b	2.56	3.28	0.92

Table E-4 (continued)

Year	Month	Power plant								Albany
		Bowline	Lovett	Indian Point			Roseton	Danskammer		
				Unit 1	Unit 2	Unit 3		Units 1 and 2	Units 3 and 4	
1975	September	1.50	11.5	103	334	31	5.07 ^b	0.00	0.45	0.13
	October	0.79	0.00	21	19	6	1.82 ^b	4.12	0.53	0.65
	November	1.42	0.21	1	2	-	7.90 ^b	1.08	1.51	0.70
	December	14.6	3.88	127	14	-	42.2 ^b	170.	528.	4.59
	January	37.0	60.8	78	13		21.0	1164.	655	1.74
	February	21.1	10.6	66	7		6.39	698.	127	0.37
	March	7.93	2.64	7	1		0.58	842.	234	0.08
	April	2.64	2.64	4	1					
	May	2.64	c	9	8					
	June	122.	7.93	100	257					
	July	5.28	21.1	38	150					
	August	c	10.6	37	177					
	September	c	2.64	-	186					
	October	c	c	-	6					
	November	c	c	-	4					
	December	c	2.64	-	19					

^aUnits for collection rate are number of fish per million cubic meters of power-plant intake flow. Y (number/ 10^6 m³) = 264.17 (gal/m³) $\times$ (number/ 10^6 gal). For the period January through September 1974, two sources of data are available for each power plant, giving number of impinged fish collected during the month and the volume of water withdrawn by the power plant during the collection periods for that month. Estimates of collection rate were calculated from each of the two sets of data; if the two results differed by 1.0 fish/ 10^6 m³ or more, both estimates were recorded in the table. In all such cases, the second entry (i.e., the one in parentheses) is based on data from ref. 1.

^bTwo conflicting estimates of power-plant intake flow were provided; the estimate that appeared most likely to be correct was used.

^cLess than 2.64 fish/ 10^6 m³.

Table E-5. Summary of available estimates of monthly collection rates for white perch for the power plants along the Hudson River for the years 1972 through 1975^a

Year	Month	Power plant								Albany
		Eowline	Lovett	Indian Point			Roseton	Danskammer		
				Unit 1	Unit 2	Unit 3		Units 1 and 2	Units 3 and 4	
1972	June			71	8					
	July			7	-					
	August			36	-					
	September			68	5					
	October			329	33					
	November			265	-					
	December			125	-					
1973	January	339.	86.1	6	842			19.5	5.53	
	February	369.	64.1	-	719			0.00	4.28	
	March	289.	216.	-	670			48.9	11.4	
	April	288.	199.	-	878			419.	19.2	
	May	256.	61.2	120	166			745.	117.	
	June	19.0	54.9	30	17			355.	100.	
	July	14.8	17.4	-	6			1050.	143.	
	August	49.8	84.6	2	28			285	22.3	
	September	6.13	14.5	0	5			448.	72.8	
	October	5.02	2.33	-	1			1445.	49.1	
	November	7.83	163.	23	40			1677.	135.	
	December	409.	379.	144	209			223.	54.4	
1974	January	1759.(457.)	402.(470.)	584	1927	-	1.16	44.2	12.6	-
	February	1220.	412.(615.)	249	1923	-	-	3.25	0.61	-
	March	970.(1142.)	510.	252	1383	27	0.35	15.3	1.95	-
	April	925.	605.(728.)	274	1275	700	148.	2255.(1926.)	232.(236.)	77.0
	May	95.1(113.)	166.(184.)	89	653	355	387. ^b	1088.(600.)	159.(101.)	95.0
	June	23.8(15.6)	39.6	24	63	62	110. ^b	852. ^b (882.)	116.(112.)	134.
	July	7.93(4.66)	10.6(8.76)	5	6	4	0.58 ^b	363.(364.)	30.9 ^b	211.
	August	5.23(3.42)	15.9	3	10	0	58. ^b (53.3)	221.	87.9	106.

Table E-5 (continued)

Year	Month	Power plant								Albany
		Bowline	Lovett	Indian Point			Roseton	Danskammer		
				Unit 1	Unit 2	Unit 3		Units 1 and 2	Units 3 and 4	
1975	September	5.28(4.05)	10.6	9	31	2	23.0 ^b	108.	30.8	178.
	October	31.7	132.	95	121	13	65.0 ^b	392.	34.6	306.
	November	581.	267.	135	392	-	176.0 ^b	322.	51.6	61.1
	December	888.	304.	927	1226	-	80.4 ^b	423.	92.9	0.35
	January	1918.	851.	1234	881		19.5	55.8	20.2	0.12
	February	97.7	122.	2319	707		15.1	26.2	14.1	0.74
	March	304.	161.	738	610		15.5	25.0	6.66	0.24
	April	1350.	547.	1295	1157					
	May	174.	26.4	142	146					
	June	15.9	29.1	18	17					
	July	18.5	7.93	19	17					
	August	5.28	39.6	19	192					
	September	2.64	26.4	-	122					
	October	2.64	31.7	-	140					
	November	21.1	542.	-	337					
	December	623.	153.	-	483					

^aUnits for collection rate are number of fish per million cubic meters of power-plant intake flow. $Y \text{ (number/10}^6 \text{ m}^3) = 264.17 \text{ (gal/m}^3) \times \text{(number/10}^6 \text{ gal)}$. For the period January through September 1974, two sources of data are available for each power plant, giving number of impinged fish collected during the month and the volume of water withdrawn by the power plant during the collection periods for that month. Estimates of collection rate were calculated from each of the two sets of data; if the two results differed by 1.0 fish/10⁶ m³ or more, both estimates were recorded in the table. In all such cases, the second entry (i.e., the one in parentheses) is based on data from ref. 1.

^bTwo conflicting estimates of power-plant intake flow were provided; the estimate that appeared most likely to be correct was used.

Sources relied on in preparing Tables E-1 — E-5 are as follows:

Bowline

January 1973 — December 1974: ref. 1, vol. II, Appendix F, Tables F-13 and F-14
 January 1975 — December 1975: ref. 2, Tables VIII-32 — VIII-36 and VIII-38
 January 1974 — December 1974: ref. 10, Table X-28 (white perch only)
 October 1974 — December 1974: ref. 10, Appendix X.A-1 (all species except white perch)

Lovett

January 1973 — September 1974: ref. 1, vol. II, Appendix F, Tables F-5 — F-12
 January 1975 — December 1975: ref. 3, Tables VIII-42 — VIII-47
 January 1974 — December 1974: ref. 10, Table X-29 (white perch only)
 October 1974 — December 1974: ref. 10, Appendix X.A-2 (all species except white perch)

Indian Point

June 1972 — December 1973: ref. 4, Tables A-3.5 — A-3.8
 January 1974 — December 1974: ref. 5, Tables B-5 — B-7
 January 1975 — December 1975: ref. 6, Tables A-6 and A-7

Roseton

July 1974 — September 1974: ref. 1, vol. II, Appendix F, Table F-19
 January 1974 — December 1974: ref. 7
 January 1975 — December 1975: ref. 8

Danskammer

January 1973 — September 1974: ref. 1, vol. II, Appendix F, Tables F-15 — F-18
 January 1974 — December 1974: ref. 7
 January 1975 — March 1975: ref. 8

Albany

January 1974 — April 1974 — March 1975: ref. 9, Tables 2 and 4

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2. 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.
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7. Lawler, Matusky, and Skelly Engineers, *Draft 1974 Hudson River Aquatic Ecology Studies at Roseton and Danskammer Point*, vol. I, 1976.
8. Letter of Transmittal for Impingement Data from January through March 1975 for Roseton and Danskammer Point Generating Stations, from Thomas Huggins, Central Hudson Gas and Electric Company, to Barbara Pastalove, U. S. Environmental Protection Agency, June 11, 1975.
9. Lawler, Matusky, and Skelly Engineers, *Albany Steam Electric Generating Station Impingement Survey (April 1974 through March 1975)*, prepared for Niagara Mohawk Power Corporation, June 1975.
10. Lawler, Matusky, and Skelly Engineers, *1974 Hudson River Aquatic Ecology Studies -- Bowline Point and Lovett Generating Stations*, prepared for Orange and Rockland Utilities, Inc., vol. 1, December 1975.

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