BEFORE THE UNITED STATES

ATOMIC ENERGY COMMISSION

In the Matter of	)	
	)	
Consolidated Edison Company of	)	Docket No. 50-247
New York, Inc.	)	
(Indian Point Station, Unit No. 2)	)	

Testimony of
John P. Lawler, Ph.D.
Quirk, Lawler & Matusky Engineers
on
The Effect of Entrainment at Indian Point on
the Population of the Hudson River Striped Bass

April 5, 1972

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I. NATURE OF THE ISSUE

Steam electric generating stations operating on the Hudson River are equipped with circulating water systems which operate on the principle of once-through cooling. Large volumes of Hudson River water are drafted from the Hudson through intakes and circulated through condensers, at which point heat from spent steam is added to this water. This steam condensation process has the effect of raising the circulating water temperature by approximately 15°F when the plant is operating at full load and the circulators are at full flow. These heated waters are finally discharged back to and mixed with the main body of the Hudson River.

At certain times of the year, the early life stages of Hudson River fishes, including the egg stage, the larval stage and the very early juvenile stage, are subject to entrainment or carriage into the circulating water system due to the fact that these stages are at least partially subject to prevailing currents in the river.

These organisms are subject to rapidly changing mechanical, thermal and pressure stresses as the water moves through the intake, the circulating water pump, the condenser, and the discharge line. As the water is lifted up to the condenser, the pressure drops rapidly below atmospheric pressure, and as heat is transferred from the spent steam, the temperature rises rapidly. These rapid changes in the variables of mechanical abrasion, pressure and temperature are thought to have an adverse effect on many of the organisms contained in the circulating water.

The effect of these stresses on the early stages of Hudson River fishes which are entrained in the circulating water flow of Indian Point Unit 1 is unknown at this time. Studies are planned for late spring and early summer of this year during the striped bass spawning and early development season. At the present time we have no quantitative information on the effect these stresses will have on entrainable life stages of the fish at Indian Point.

Studies at other locations have shown both damage and no damage upon entrainment[(1),(2),(3),(4),(5)]. Although some damage may be expected, the actual quantitative amount and level of such damage at any given station is almost impossible to predict without direct measurement at that station. Condenser pressure and temperature rise, exposure time, species and life stage, water quality and ambient water temperature appear to be some of the variables controlling entrainment damage and mortality. For these reasons, quantitative evaluation of the damage must await the results of this year's planned study effort at Indian Point, to be executed during the spawning and summer growing season of the Hudson River striped bass.

Since the actual effect of Indian Point entrainment on mortality of these stages is unknown at this time, QL&M has attempted to develop an analytical means to evaluate not only the potential for direct loss of eggs, larvae and early juveniles from the River fishery, but also the potential impact on the River's adult population. In other words, rather than simply considering the number or percentage of organisms in any stage that may be removed from the River system, we are more concerned with the ultimate impact of this removal on the River fishery population. This evaluation is the subject of this report.

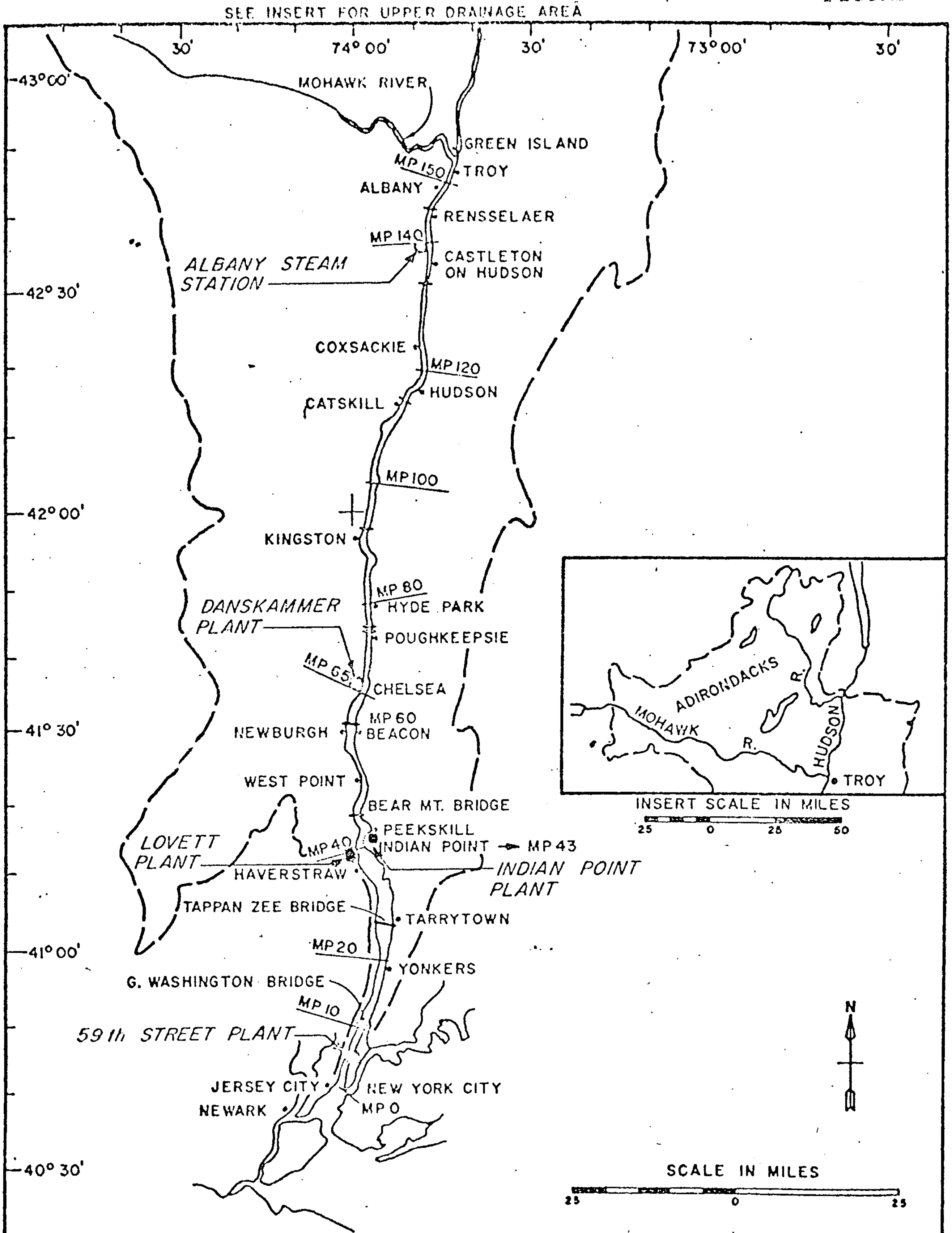
II. SPECIFICS CONSIDERED

This study has been primarily directed at the impact of the Indian Point nuclear generating station on the Hudson River striped bass population. The existing Unit No. 1 and the proposed Unit No. 2 are both included in the evaluation. The roles of other existing generating units on the River are also considered.

The methodology employed is applicable to other estuaries as well as to other species of fish. The striped bass has been singled out for this study because, with respect to the Hudson River, more information is available on this species than on most other species common to the River, and also because the striped bass is generally considered to be the species of greatest importance and interest in the Hudson River.

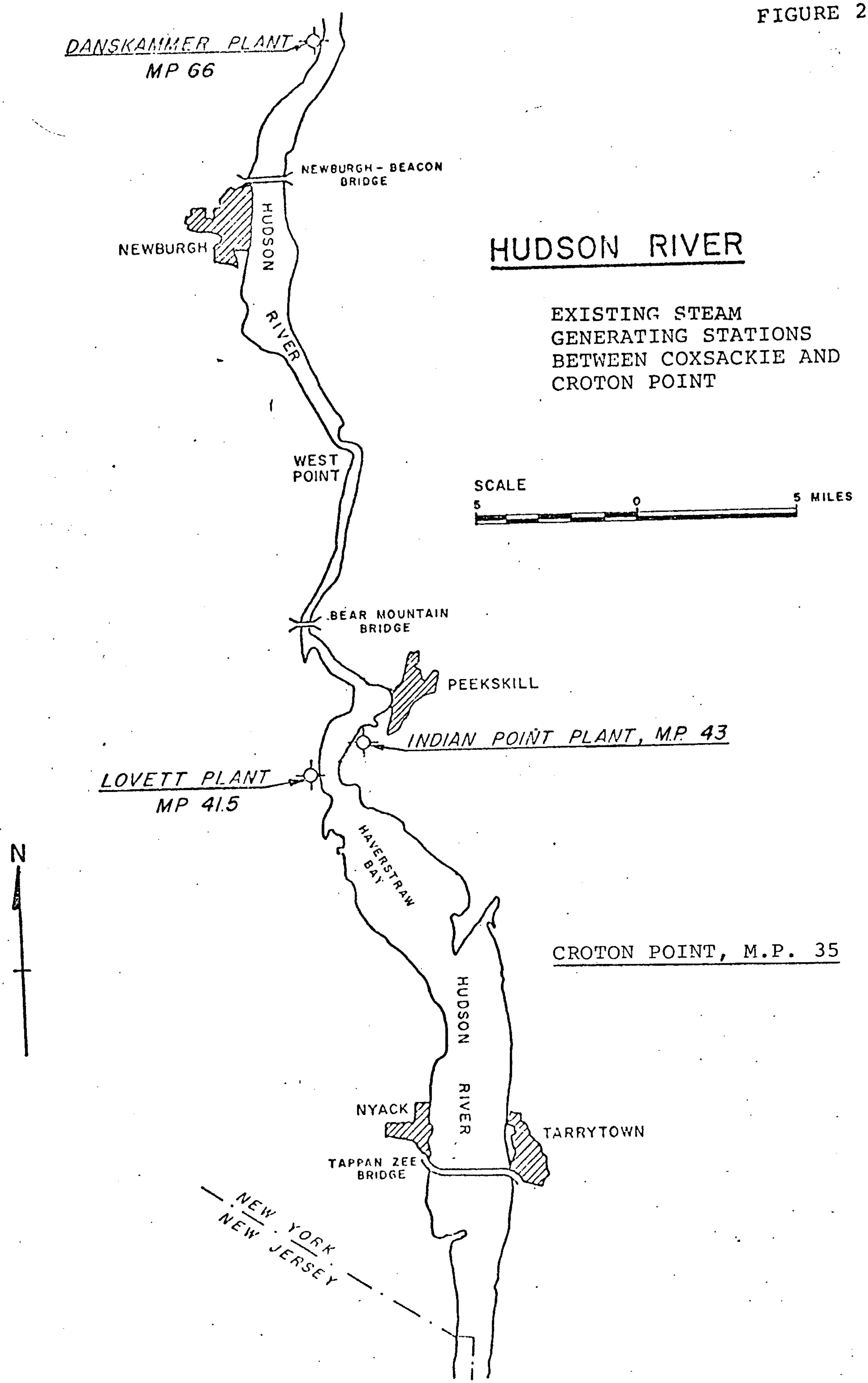
Figure 1 is a map showing the location of existing electric generating stations along the Hudson River. Figure 2 is a map showing the location of Indian Point and of those existing generating stations which are located within the reach of the River between Coxsackie and Croton Point, within which the entrainable stages of the striped bass have been observed (6), (7) to appear.

FIGURE 1



EXISTING HUDSON RIVER STEAM ELECTRIC POWER GENERATING STATIONS

FIGURE 2



DANSKAMMER PLANT
MP 66
NEWBURGH - BEACON BRIDGE
NEWBURGH
HUDSON
RIVER
HUDSON RIVER
EXISTING STEAM GENERATING STATIONS BETWEEN COXSACKIE AND CROTON POINT
WEST POINT
SCALE
5
0
5 MILES
BEAR MOUNTAIN BRIDGE
PEEKSKILL
INDIAN POINT PLANT, M.P. 43
LOVETT PLANT
MP 41.5
N
HAVERSTRAW BAY
CROTON POINT, M.P. 35
HUDSON
RIVER
NYACK
TARRYTOWN
TAPPAN ZEE BRIDGE
NEW YORK
NEW JERSEY

Existing generating plants of interest in this study include Orange & Rockland Utilities' Lovett generating station, located on the west bank of the Hudson River approximately 1.5 miles below Indian Point, Central Hudson Gas & Electric Company's Danskammer station, located on the west bank of the Hudson River just north of Newburgh and approximately 23 miles north of Indian Point, and Consolidated Edison's Indian Point Unit No. 1 facility, located on the east side of the Hudson River about 43 miles north of the Battery.

Niagara Mohawk's Albany steam station in Glenmont, New York and Con Edison's 59th Street station in mid-Manhattan, are considered to have no effect on the entrainable stages of the striped bass. This occurs because striped bass eggs, larvae and young juveniles are not observed either north of Coxsackie, New York, which is below the Glenmont generating station, or south of Haverstraw Bay and the Tappan Zee, which is north of the 59th Street Station.

Table 1 shows the operating characteristics of these generating stations.

Entrainable stages of the striped bass life cycle include the eggs which appear in the River for a period of 1.5 to 3 days before hatching or dying by natural means, the larval stage which progresses through a series of steps for approximately 21 days, during which the fish passes from the planktonic to the swimming stage and at the end of which the young fish has reached a size of about one inch, and the very early juvenile stage lasting for 4 to 7 weeks beyond the larval stage, at

TABLE 1

Existing Hudson River Steam Electric Generating Stations

Station Name	Location Village or Town	Location Mile Point	Utility Owner	Number of Units	Rated Capacity all units (Megawatts)	Total Plant Flow, (gpm)	Plant Temperature Rise at Rated Capacity (°F)
Albany	Glenmont	140	Niagara Mohawk Power Corp.	4	400	352,000	11.0
Danskammer	Newburg	66	Central Hudson Gas & Electric	4	508	308,000	14.5
Lovett	Stony Point	42	Orange & Rockland Utilities	5	503	323,000	14.8
Indian Point #1	Buchanan	43	Consolidated Edison Co. of New York	1	265	318,000	14.0
Indian Point #2	Buchanan	43		1	873	870,000	15.1
59th Street	New York City	5	Consolidated Edison Co. of New York	7[1]	221[1]	168,000	6.0[2]

[1]Of this total, 4 units, totalling 91 MW, do not employ condenser but provide steam for in-city use.

[2]Monthly average operation, summer, 1969.

which time the fishes have reached a length of about 2 inches (Mansueti (3), Carlson (7) and Pearson (8)).

At this point, it is presumed that the fish is no longer subject to entrainment effects. The next section discusses the development of the basic analytical model which has been used to evaluate the effect of entrainment on the entire life cycle.

III. DEVELOPMENT OF THE ANALYTICAL MODEL

Figure 3 depicts the basic life cycle upon which the analytical model is based.

We begin with the egg stage which is shown as the top circle in the cycle on Figure 3, and recognize the appearance of vast numbers of eggs in the river at the time of spawning. A large percentage of the eggs never survive this stage, being subject to natural mortality via settlement into bottom muds, lack of fertilization, predation, etc. These losses are depicted on Figure 3 by the double arrow directed outward from the cycle at the egg state.

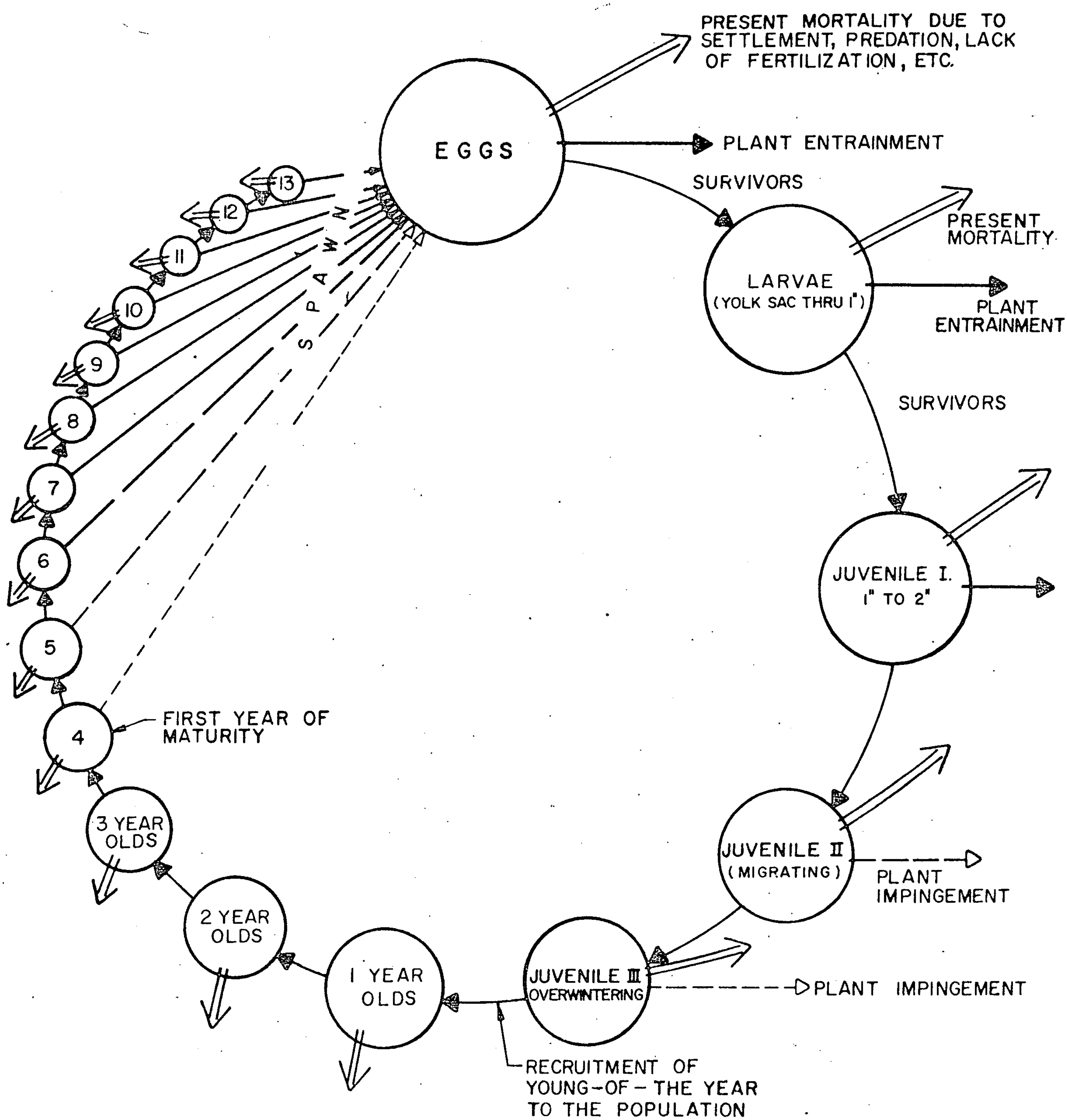
The term "present mortality" has been employed in this and successive stages to represent mortality that now takes place in the River, whether due to natural or artificial causes.

This first stage is also subject to entrainment and some presumed resultant mortality, when within the influence of plant intakes. This effect is depicted by a single bold arrow, also directed outward from the cycle at the egg stage.

Those eggs which survive are shown on Figure 3 as being transferred into the larval or next stage of the cycle.

Similar behavior of present and plant-induced mortality, and survival and passage into the next stage is shown in the next several stages, i.e., the larval and juvenile stages. Plant-

SCHEMATIC LIFE CYCLE FOR STRIPED BASS IN THE HUDSON RIVER



induced mortality is shown to include impingement on fish screens as well as entrainment into the circulating water system.

It is realized that, biologically, the juvenile stage lasts until the attainment of sexual maturity. For the striped bass, the first significant female maturity is believed to occur in the four year old fish. We have used the term "juvenile" in this report, however, to represent only that stage of the life cycle between the larval stage and the completion of the first year of life. These "juveniles" are potentially subject to damage by the plant.

After reaching the age of one year, the fish are generally hardier, the rate of true natural mortality is probably substantially lower, and the fish are no longer subject to entrainment, nor, for the most part, impingement. These developing adults, therefore, are not themselves subject to damage by the plant.

The population of these immature fish has been lumped together with the mature adult population, and the abbreviated term, "adult population" employed to represent all fish one year old or more. These two groups, taken together, represent the bass population that, although not directly subject to damage by the plant, may yet feel the impact of direct damage to early stages; i.e., the population of one year olds and above may experience a reduction due to losses by entrainment and impingement in the early stages.

Adult stages are shown in Figure 3 for each year of life, beginning with age group I. Present mortality is shown to remove a certain amount of adults from each year class as their age increases from year to year. No plant-induced mortality has been shown in these stages since the fish are too large to be entrained and data on fish impingement at Indian Point suggests that fish impingement has only a relatively small influence on adult mortality.

Some four year old females are sexually mature and from that point on, adults are shown in Figure 3 to be contributing to the egg complement, thus completing the cycle.

It was stated above that the double arrow leaving each life stage shown in Figure 3 represents "present mortality; and includes natural factors such as settlement of eggs into bottom muds, predation of larvae by adults of other species, etc., and artificial factors.

In addition to the usual natural mortality factors, the "present mortality" term includes that portion of migration out of the Hudson River which is not followed by a return in the following year. The reason for inclusion of this "loss" in the existing mortality term is given in the following section of this testimony.

Artificial factors in the "existing mortality" term include the effect of pollution and man's use and alteration over the past century or more of shallows, shoals and shoreline, as well as direct exploitation of the adult population by commercial and sport fishing.

We also consider losses caused by the circulating water systems of existing Hudson River generating stations to be included in the term "present mortality."

Although the schematic in Figure 3 lumps all existing losses in each stage as one term, the mathematical model can be structured to handle each of these effects individually, in each stage of life. Alternatively, some can be lumped and only certain ones chosen for individual assessment. Data or estimates on loss must be available for each of those factors chosen for individual assessment.

Some of these natural and artificial factors are exceedingly difficult to quantize on an individual basis. Others, such as exploitation by sport and commercial fishing, can be estimated. Estimates of the relative effect of sport and commercial fishing, by comparison to the potential plant effect, are made in later chapters of this report.

Each of the elements contributing to the basic life cycle shown in Figure 3 can be quantized, the result of such being the construction of a mathematical model which yields a quantitative description of the schematic shown in Figure 3. The step-wise model development is shown below, with emphasis placed on the conceptual, the analytical, and empirical notions necessary to this development.

The first step in the development is the introduction of two conceptual notions. These are the completely mixed model and the notion of equilibrium.

The Notion of Complete Mixing

A complete description of striped bass behavior in the Hudson River requires an extremely complex model which would include the ability to move through the life cycle, taking into account at each stage the many factors which influence that stage, and at the same time, the ability to move from section to section along the River and from shore to shore and top to bottom at any section.

Such a model requires refined knowledge of the kinetics of the life cycle of the bass, including such things as competition with other species, the influence of variable levels of pollutants, and the driving forces which compel the fish to seek shallows at one time, deep waters at another and so on. Additionally, the physical transport mechanisms including freshwater, tidal and salinity-induced currents, the variations of these currents along the River, and the influence they exert on the fishes' behavior would also be required.

The degree of refinement that might be desirable to consider is almost without limit. As in any modelling effort, however, there are the practical considerations (1) of the data available to permit deduction of behavior and (2) of the tractability of the mathematics required as refinements increase. These considerations require that model development begin with a model for which there is reasonable expectation that the questions raised about the system are being viewed realistically, and that the equations used to describe the system can be solved.

Rather than complicate the issue at this point by including the known variable behavior of each stage along the River's length, as well as in the vertical and lateral directions at any river cross-section, we have viewed the river as a completely or totally mixed volume of water in which the concentration or density of any life stage is the same at all points throughout that water volume. This view permits substantive simplification of the required mathematics and allows the analyst to focus on the key question of kinetics, or the quantitative description of survival and transfer from one stage to the next.

Treatment of variation along the River's longitudinal, vertical and lateral axes is presently under development. This transport model, and items to be included in it is discussed below after establishing that the totally mixed model is a valid first approach.

The assumption of complete mixing is considered to be conservative because it forces every organism in the River to be equally subject to entrainment, whereas in reality, only those organisms which pass Indian Point while they are in the entrainable stage and which do not avoid the plant are subject to entrainment by the Indian Point station.

We shall show that the actual percentage of the River's population that is subject to entrainment is a function of the relationship of plant flow to natural mortality over the whole system. Were a transport model employed, this relationship would be shown to be lower, since, in addition to natural mortality, convection and dispersion of Hudson River water past the plant and the movement preferences of the young motile fishes would also appear in the term against which plant flow is compared.

This notion of complete mixing is not meant to eliminate consideration of spatial variation of striped bass, eggs, larvae and juvenile behavior in the Hudson River. Such variation has been considered in two preliminary transport models, in which the Hudson River transport mechanisms of tidal mixing, salinity-induced circulation, and freshwater movement were all included.

Comparison of larval entrainment results obtained using these preliminary transport models to those obtained using the complete mixing model shows that the complete mixing assumption is conservative; i.e., the transport model (no fish motility included) shows about 15% less entrainment of the entrainable population than does the completely mixed model. Both of these preliminary transport models considered steady conditions only, neither considered passage of survivors to the next stage, and both used a fixed rate of natural larval mortality. The comparison was made by applying these restrictions to the completely mixed model.

The Notion of Equilibrium

Virtually every natural population is subject to variation from year to year and the striped bass population in the Hudson River is no exception. This variation can be explained in terms of variation in the key environmental factors that control a population. Striped bass spawning and early growth, for example, are known to be dependent on photoperiod, water temperature, salinity, level of pollution, mixing intensity, etc., all of which can vary substantively from year to year during the spawning and early development season.

The literature (9), (10) on east coast striped bass populations is quite emphatic in its descriptions of the so-called "super year class," examples of which occurred in 1934 and 1942 in the Chesapeake Bay - Delaware Bay region and had their influence on striped bass populations along the east coast for years afterwards. The appearance of such year classes is often described as the result of "everything was right" in terms of the various environmental factors which influence these stages. This natural variation in the population from year to year can fluctuate about a long term equilibrium population or can be superimposed on either a growing or a declining situation.

There is some evidence (11) of a gradually increasing population of striped bass in the Hudson River, which various commentators have suggested may be the result of gradually improving water quality and less pollution. There does not appear to be, however, any hard and conclusive evidence at this time as to which of these three long term situations is taking place with respect to striped bass populations in the Hudson River.

For purposes of this study, we have presumed that the River's striped bass population is at equilibrium in the long range sense, and that variations in the population from year to year are negligible. These assumptions are made to simplify the mathematics and do not abrogate the basic objective of preparing an analytical description of the life cycle and of the effect of entrainment by a plant on that cycle.

The same analytical approach could be applied to a growing or declining population, and variation about the long range condition, whatever it is, can also be handled. In point of fact, after development of the basic model, we show one method by which fluctuations about equilibrium from year to year can be demonstrated, as well as how a growing or declining population may be described.

Basic Notion of Survival and Passage to Next Stage

This section presents the mathematical formulation of behavior within a given stage. The mechanisms of generation, natural mortality, plant-induced mortality, and finally survival and subsequent passage into the next stage are considered.

Choose the egg stage for this illustration. Let the average rate of spawning over a small period of time, dt, be given by P'(t), in which:

P'(t) = number of eggs spawned, or dropped into a unit volume of the water body per day.

Then let the number[1] of eggs actually spawned in the small period dt be given by N_{E_o} and obtain:

$$N_{E_o} = P'(t)dt$$

Now track the fate of N_{E_o} through the day to three days of the striped bass egg stage during which either mortality occurs or the organism survives and becomes designated as having passed into the larval stage.

1 Actually concentration, or number per unit volume since P'(t) is also on a unit volume basis.

From the moment of spawn on, the number of viable eggs remaining at any time t out of the original complement given by N_{E_o} is continuously decreasing. Let this number be written $N_E(t)$. The rate of change of numbers of eggs is given by the derivative, $\frac{dN_E(t)}{dt}$ so that we now have:

N_{E_o} = number of eggs dropped at time zero

$N_E(t)$ = number of viable eggs remaining at any time "t" out of original complement, N_{E_o}

$\frac{dN_E(t)}{dt}$ = time rate of change of $N_E(t)$

Now recognize that those mechanisms responsible for change in the concentration of eggs in the River include natural mortality, plant entrainment and passage out of the River. Thus we may write:

$$\frac{dN_E(t)}{dt} = \begin{array}{c} \text{Rate of Loss by Natural Mortality} \\ + \\ \text{Rate of Loss by Plant Entrainment} \\ + \\ \text{Rate of Transport In or Out of the System} \end{array}$$

Since we are interested in focusing only on the kinetics of the life cycle, and not on transport in or out of a particular reach of the River, we define that the reach of the River under observation is the entire stretch along which eggs are observed. In other words, the egg concentration drops to zero at each end of the reach in question, so that no eggs can be transported in or out of the reach under study. Since we have already made the simplification of complete mixing, we are actually looking at the average egg concentration over the whole reach of the River within which spawning is known to occur.

The actual reach used in this study stretches between Croton Point at the downstream end, a point 35.5 River miles north of the Battery, to Coxsackie at the upstream end, a point 125 River miles north of the Battery. The volume of this reach of the Hudson River is .391 cubic miles or roughly 60 billion cubic feet (57.35 BCF).

For purposes of model development, the rate of decay by natural mortality in each life stage has been presumed to follow first order kinetics; i.e., the rate of reduction of concentration of organisms in any stage is proportional to the concentration of viable organisms remaining.

$$\text{Rate of Loss by Natural Mortality} = -K_E N_E$$

Natural decay of a biological population in accordance with first order kinetics is a common phenomenon and has been reported in describing many biological systems (12), (13), (14). A common mechanism which exhibits this behavior is the case of the organism (eggs, larvae, early juveniles) in question as prey, given a fixed number of predators. The time rate at which 50 of these organisms per unit water volume will be observed to be disappearing from a given system will be one-tenth the rate at which 500 such organisms will be disappearing in the process of being removed.

There are, of course, controls which will alter the rate dependence; in the example above, the system can become saturated with prey and there will be a food concentration above which the rate of predation will be independent of the concentration of prey. This is explained by recognizing a maximum rate at which the predators can physically catch and consume food. Regardless of how much is available above this level, the predation rate cannot increase. Mortality kinetics for this situation are termed zero order, with respect to the organism concentration; i.e., the rate of mortality is independent of, and therefore constant, as far as organism concentration is concerned.

The effect of other than first order kinetics on the fish life cycle model is currently being investigated and is discussed to some extent in a later section of this testimony. We show, for example, that this linear mortality rate, in the feedback system being considered, is highly conservative, since it will lead to extinction of an equilibrium population under any additional sustained exploitation, however small. An analytical description of the density-dependent and compensatory reserve mechanism, which may control juvenile mortality in nursery areas such as Haverstraw Bay (15), is also given.

The rate of loss by plant entrainment is quantitatively written as the product of the circulating water flow, "Q_p," the concentration of organisms in the intake water, "N_E", and the fraction of organisms entrained that are actually killed or suffer irreversible damage, "f_E".[1]

Rate of Loss by Plant Entrainment = $-f_E N_E Q_P$

The time rate of change of organism concentration is then written:

$$\frac{VdN_E}{dt} = -K_E N_E V - f_E N_E Q_P \qquad (1)$$

The term "V" represents the volume of the River reach in question. The River volume must be included since the loss by entrainment is a rate phenomenon, having units of numbers of organisms lost per day and must be compared against the total rate of natural mortality, rather than the mortality rate per unit volume. The expression "$K_E N_E$" represents natural mortality per unit volume since "N_E" represents number of eggs per unit volume.

Solution of equation 1, subject to the initial condition that at time zero, the concentration of eggs present in the system is N_{E_o}, is written:

$$N_E(t) = N_{E_o} e^{-\left(K_E + \frac{f_E Q_P}{V}\right)\Delta t_E} \qquad (2)$$

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1. In chapter VI, "f" is also assumed to include that fraction of a stage that is not capable of avoiding the intake.

Equation 2 yields the concentration of eggs out of the original complement N_{E_o} still viable at time t. If the period of existence in the egg stage before passing to the larval stage is given by Δt_E, then the number of survivors out of the original complement N_{E_o} which then become larvae is:

$$N_E(\Delta t_e) = N_{E_o} e^{-(K_E + \frac{f_E Q_p}{V})\Delta t_e} \tag{3}$$

Or in terms of the original production rate, P'(t), the surviving concentration is given:

$$N_E(\Delta t_E) = P'(t) \cdot e^{-(K_E + \frac{f_E Q_p}{V})\Delta t_E} \cdot dt \tag{4}$$

Now recognize that eggs are being spawned daily for a period of five to six weeks. Call the total spawning period T_E. The total number of survivors of the egg stage is then written:

$$\Sigma \begin{matrix}\text{Egg Stage}\\ \text{Survivors}\end{matrix} = V \int_0^{T_E} P'(t) \cdot e^{-(K_E + f_E Q_p/V)\Delta t_E} \cdot dt \tag{5}$$

This also represents the initial number of larvae. Notice that this two-step approach to the determination of total egg stage survivors (determination of survival fraction for the single complement dropped over the small time increment, dt, followed by integration over the total period of spawn, T_E) is valid when first order kinetics are employed because the unit decay rate, K_E, is independent of egg concentration, and thus the appearance of more eggs dropped during the next dt interval will not affect the computation of the number of survivors of the first complement. Additional complexity in computing survival is to be expected when compensatory, i.e., density-dependent or non-linear, rate mechanisms are employed.

The foregoing results suggest the construction of the basic life cycle model. The production form in each stage is simply the survivors of the previous stage. First order decay is presumed in each stage so that the decay terms for each stage are similar. For example, the expression for the larval stage survival is written:

$$\Sigma \begin{matrix}\text{Larval Stage} \\ \text{Survivors}\end{matrix} = V \int_{\Delta t_E}^{T_E+\Delta t_E} P'(t-\Delta t_E)\, e^{-K_E' \Delta t_E} \cdot e^{-K_L' \Delta t_L}\, dt \qquad (6)$$

in which time "t" is measured from the initiation of spawning. Based on data presented in Carlson's Cornwall report (7), we have chosen May 9 of any given year to represent the initiation of striped bass spawning, so that, in subsequent sections, t = 0 refers to May 9.

Notice that in equation 6, the argument $(t-\Delta t_E)$ may be replaced by $\bar{t}$ and equation 6 rewritten:

$$\Sigma_{\text{Survivors}}^{\text{Larval Stage}} = V\int_0^{T_E} P'(\bar{t})e^{(-K'_E\Delta t_E - K'_L\Delta t_L)}dt \tag{7}$$

Now, since $\bar{t}$ is simply a dummy variable, the over-bars may be dropped and equation 7 rewritten:

$$\Sigma_{\text{Survivors}}^{\text{Larval Stage}} = V\int_0^{T_E} P'(t)e^{(-K'_E\Delta t_E - K'_L\Delta t_L)}dt \tag{8}$$

The parameters K'_E and K'_L are simply the unit mortality rates in the totally mixed system for the egg and larval stages, respectively, and are given by:

$$K'_E = K_E + \frac{f_E Q_p}{V} \tag{9}$$

$$K'_L = K_L + \frac{f_L Q_p}{V} \tag{10}$$

For the base case of no plant operation, $Q_p = 0$ and $K' = K$, the natural mortality rate in any stage. Notice that the mortality rates in the totally mixed system are additive, so that the effect of plant operations may be estimated by comparing the relative magnitudes of K and $\frac{fQ_p}{V}$.

In the next section, we shall be interested in completing the life cycle model by computing the number of fertile female adults from age one year through an arbitrary 13 years, and multiplying the numbers in each year of life by the associated fecundity (number of eggs/female) to determine each calendar year's total egg complement.

Completion of the Life Cycle Model

We begin by writing the expression for the number of juveniles about to be recruited into the adult population on May 9 of the year following their birth. The model views adults and their associated survival on a year by year basis, so that on May 9 of each year, each survivor from age group 0 through age group 12 is advanced to the next age group. This results in an adult age distribution of one to 13 years. By analogy to Equation 8, the number of surviving juveniles at the point they are recruited into the adult population is written:

$$N_1 = \int_0^{T_E} P'(t) \exp(-K'_E \Delta t_E - K'_L \Delta t_L - K'_J \Delta t_J)\, dt \qquad \text{........(11)}$$

Now the mathematical treatment of Equation 11 is slightly more complex than that of either Equations 5 or 8. We have chosen to set the duration of the egg and larval stages, Δt_E and Δt_L, as constants equal to 1.5 and 21 days respectively. This, of course, is a simplification of the real life case, in which the actual life of any surviving egg and larval organism may range, for the egg, from 1.5 to 3 days, depending on the water temperature, and for the larval, from perhaps 10 to 30 days. The latter case is further complicated by the definition of the larval stage. Our selections are discussed in greater detail in Chapter IV.

Thus, the 1.5 and 21 day life periods must be looked at as averages, descriptive of each stage. This is perfectly proper relative to the modelling objective and the type of model being developed.

The juvenile stage has two additional complications. First of all, the period of life from 3 to 4 weeks after spawning through almost a full year's development encompasses too many stages, each with its own particular vulnerability to entrainment, to employ a single mortality factor (K_J).

Secondly, for the model to be internally consistent mathematically, we must treat Δt_J as a variable, not a constant, if we wish to age all survivors on a fixed date, such as May 9. The reason for this is that survivors of the juvenile stage have lived in the River for varying periods of time, since they can have come from eggs dropped at any time between May 9 and June 15 (T_E has been chosen as 37.5 days).

We will return to the precise treatment of the juvenile stage some paragraphs below, after showing the basic remaining steps in the construction of the life cycle model.

Knowing N_1, Equation 11, the population of the one year old age group at the beginning of that first year of adulthood, the population of successive age groups of adults can be obtained as follows:

$$N_i = N_{i-1} \exp(-K_{i-1} \Delta t_{i-1}) \qquad \text{.......(12)}$$

in which:

N_i = the number of fish in the ith age group at beginning of the ith year.

N_{i-1} = the number of fish in the (i-1)th age group at beginning of the (i-1)th year.

K_{i-1} = first order mortality rate to which the (i-1)th age group is subject.

Δt_{i-1} = 365 days or one year

i = 2, 3, 4, 5, ..., 13

The term, $e^{-K_{i-1} \Delta t_{i-1}}$ represents the fractional survival from one year to the next, or the fraction of the (i-1)th population that makes it through the (i-1)th year. Therefore, the number of fish in any given age group is:

$$N_i = N_1 \exp\left(\sum_{j=1}^{i-1} -K_j \Delta t_j\right) \qquad \text{..........(13)}$$

in which j=1 ... i-1, the number of age groups, from one year olds to (i-1) year olds, involved in the computation of the number of ith year olds, N_i and i=2,.......,13.

For example, the number of four year olds in the population is given:

$$N_4 = N_1 \exp -(K_1 \Delta t_1 + K_2 \Delta t_2 + K_3 \Delta t_3) \qquad \text{.........(14)}$$

As an example, presume 50% survival in each of the three years. Equation 14 then yields:

$$N_4 = N_1 (0.5 \times 0.5 \times 0.5)$$

or the contribution of any given calendar year class has been reduced to 12.5% of its original recruitment to the adult population by the beginning of the fifth year of life, i.e., at the point where a fish is fully four years old.

The total adult fish population on May 9 of any given year is then written:

$$\sum_{i=1}^{13} N_i = N_1 \left(1 + \sum_{i=2}^{13} e^{-\sum_{J=1}^{i-1} K_J \Delta t_J}\right) \quad \ldots\ldots\ldots\ldots (15)$$

Since N_1 is known in terms of total spawn and survival through the juvenile stage (Equation 11), total population can be reduced to a product of spawn and survival through all subsequent life stages. To show this, substitute Equation 11 into Equation 15 and obtain:

$$\sum_{i-1}^{13} N_i = \left\{ \int_0^{T_E} P'(t) \exp(-K'_E \Delta t_E - K'_L \Delta t_L - K'_J \Delta t_J)\, dt \right\} \left(1 + \sum_{i=2}^{13} e^{-\sum_{J=1}^{i-1} K'_j \Delta t_j}\right) \quad \ldots\ldots\ldots (16)$$

Now we can come full circle by realizing that total egg count is given by accounting for the total number of spawning females and their associated fecundities. This is written:

$$\int_0^{T_E} P'(t)\,dt = \sum_{i=1}^{13} N_i\, f_{s_i}\, f_{m_i}\, F_i \qquad \text{............ (17)}$$

in which:

N_i = ith year class

f_{s_i} = fraction of females within N_i

f_{m_i} = maturation or fraction of sexually mature females within N_i

F_i = average fecundity of N_i or eggs/mature female

Given survival information (a knowledge of K and Δt) for each life stage, fecundity data (f_{s_i}, f_{m_i}, F_i) for each adult age group and spawn data ($P'(t)$, T_E) for a given year, Equations 11, 13, 15 and 17 can be solved for N_1, any N_i, egg production, and total population for a succession of years afterwards.

Depending on the relative balance between the known (or assumed) parameters, the model may show the population to be in either a growing, declining or equilibrium state. If imbalanced (not in equilibrium), growth or decline will continue unless compensated for, a notion discussed in a later section.

Now, as discussed previously, we are particularly interested in the condition of equilibrium, since it will permit simplification of the mathematics, and also since it seems to be a good frame of reference from which departures, due to plant impact, can be evaluated.

The equilibrium condition is obtained using Equations 11, 13 and 17, by recognizing that this condition of equilibrium will require that P'(t) must remain constant from calendar year to calendar year. Thus, the new P'(t) generated by spawning females in Equation 17 must be identical to the original P'(t) which appears in Equation 11.

Begin by defining $\overline{P'(t)}$ as the average spawning rate over the spawn period T_E and rewrite Equation 17 as:

$$\overline{P'(t)}\, T_E = \sum_{i=1}^{13} N_i\, f_{s_i}\, f_{m_i}\, F_i \qquad \text{.............(18)}$$

Now assume that P'(t) in Equation 11, although actually time variable, may be replaced by the average spawning rate $\overline{P'(t)}$. Since the functional form of P'(t) is reasonably well known, the effect of this assumption can, and is being investigated. We believe that this assumption will exert little real change in the equilibrium conditions, by comparison to the result which would be obtained by rigorous treatment of the integral in Equation 11, because the exponential weighting function itself is virtually constant in that integral.

Equation 11 can now be rewritten:

$$N_1 = \overline{P'(t)} \int_0^{T_E} \exp\left(-K'_E\, \Delta t_E - K'_L\, \Delta t_L - K'_J\, \Delta t_J\right) dt \qquad \text{........ (19)}$$

and Equation 13 becomes:

$$N_i = \overline{P'(t)} \left\{ \int_0^{T_E} \exp\left(-K'_E\, \Delta t_E - K'_L\, \Delta t_L - K'_J\, \Delta t_J\right) dt \right\} \exp \sum_{j=1}^{i-1} -K_j\, \Delta t_j \qquad \text{..........(20)}$$

in which we let i=1, 2, 3, ..., 13 and in which $\sum_{j=1}^{0} -K_j \Delta t_j$ is defined as zero. This permits inclusion of all age groups in the same expression.

Substitute the right side of Equation 20 for N_i in Equation 18, recognize that the $\overline{P'(t)}$ are equal for the equilibrium condition and obtain:

$$1 = (T_E^{-1}) \int_0^{T_E} \exp\left(-K'_E \Delta t_E - K'_L \Delta t_L - K'_j \Delta t_j\right) dt \sum_{i=1}^{13} f_{s_i} f_{m_i} F_i \exp - \sum_{j=1}^{i-1} K_j \Delta t_j \quad \text{.............(21)}$$

This equation of equilibrium has been utilized in this study, as will be described in the next section, to define the present condition of the River, and to serve as a basis for the evaluation of the impact of the plant on the River striped bass population.

Treatment of the Juvenile Stage

The integral used to evaluate survival through the first year of life is given in Equation 19 and contains the time variable juvenile suvival term, $\exp(-K_J \Delta t_J)$. As discussed previously, any given juvenile may make its first appearance in the River between a point 22.5 days ($\Delta t_E + \Delta t_L$) beyond May 9 (May 31) to a point 5 - 6 weeks beyond May 31, or July 7 ($\Delta t_E + \Delta t_L + T_E$), where T_E is assumed to be 37.5 days.

Secondly, it was pointed out that the period of life, from early summer to May 9 of the following year, encompassed a long period during which the influence of the plant on these juveniles might vary considerably.

These considerations have resulted in the following mathematical treatment of the juvenile stage. Supporting documentation for the various time periods chosen is given in Chapter IV, under selection of parameters.

Time periods associated with all of the early life stages are given in Figure 4.

Three consecutive sub-stages of the juvenile stage are recognized, as shown in Figure 3. These are:

1. The Juvenile I stage, J_I, or so called non-screenable juveniles. This stage begins at the end of the 21 day larval stage and continues for one month (30 days). This has been chosen as the length of time during

STRIPED BASS DEVELOPMENT FROM FERTILIZED EGG TO ONE YEAR OF AGE

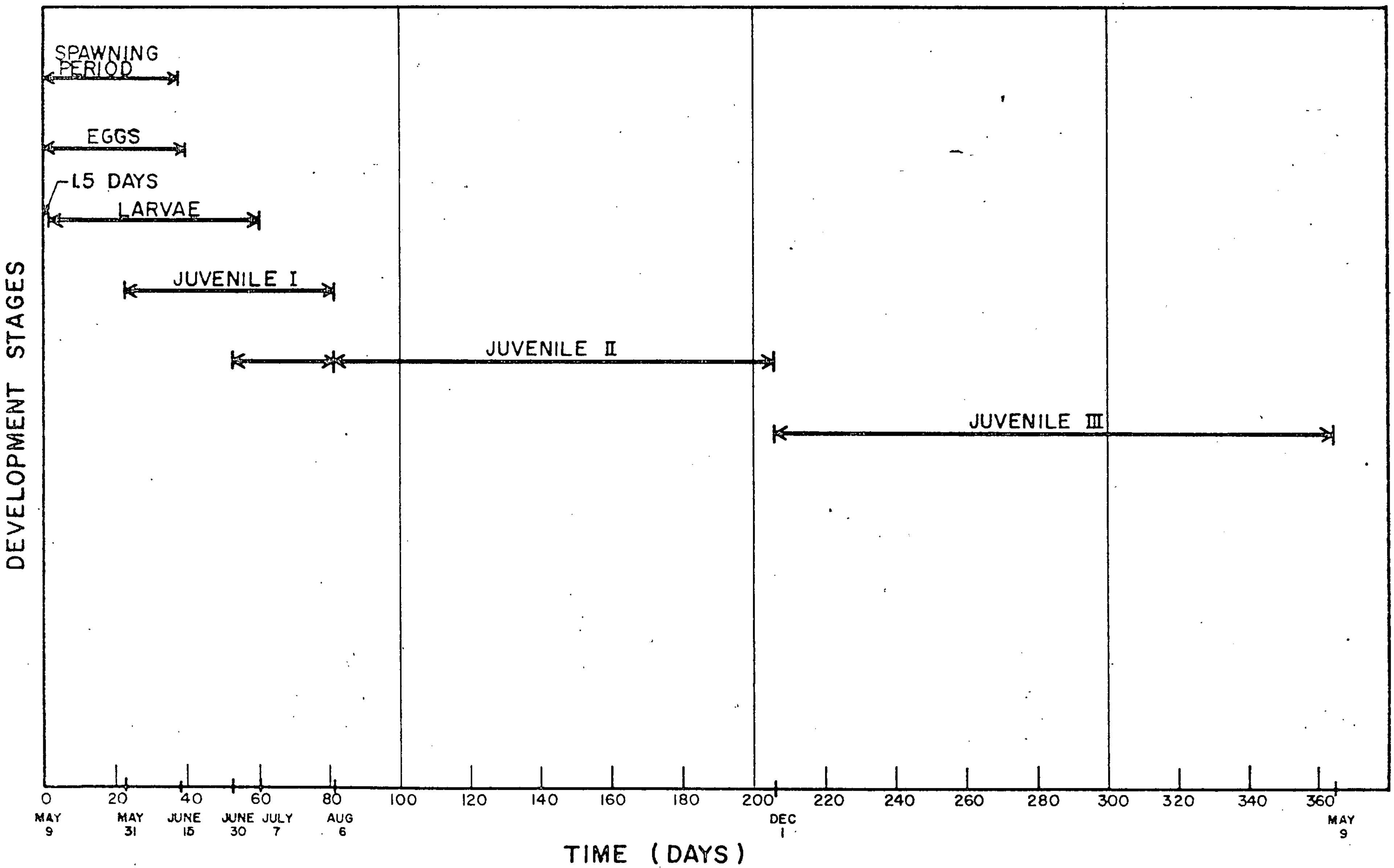


FIGURE 4

which juveniles are still entrainable, or non-screenable. At the end of the 51 day post-egg development stage, the young juveniles have reached approximately 2 inches in length and at that point are no longer considered non-screenable.

2. The Juvenile II stage, J_{II}, beginning at the end of the J_I stage and lasting through November 30. These are termed screenable juveniles, migrating mode, and represent the young of the year which appear in nursery areas along the River between Coxsackie and Croton Point from mid to late summer and then in the fall begin to move down River toward Haverstraw Bay.

3. The Juvenile III stage, J_{III}, overwintering in the River, probably primarily in the region of Haverstraw Bay, between December 1 and May 9.

Notice that every surviving juvenile in the J_I and J_{III} stages has lived through each of these stages for the same period of time as any other in the stage. These periods are:

$\Delta t J_I$ = 30 days

$\Delta t J_{III}$ = Dec. 1 to May 9 = 159 days

Surviving J_{II} juveniles live in that stage for varying periods of time. The earliest point at which individuals in this stage first appear is June 30 or 52.5 days after May 9 and the latest first appearance is made T_E weeks later, or on August 6. Any surviving J_{II} juvenile, therefore, may have existed in that stage between 116 days and 153.5 days.

Equation 19 then is written:

$$N_1 = \overline{P'(t)} \int_0^{T_E} \underbrace{\exp[-K_E'\Delta t_E - K_L'\Delta t_L - K_{J_I}'\Delta t_{J_I} - K_{J_{III}}'\Delta t_{J_{III}}]}_{\text{a constant}} e^{-K_{J_{II}} f(t)} \cdot dt \qquad (22)$$

in which:

$f(t) = [t_{II,III} - t_s] - [\Delta t_E + \Delta t_L + \Delta t_{J_I}] - t$

$t_{II,III}$ = calendar date at which all remaining J_{II} are classified as J_{III}

t_s = calendar date at which spawning begins

$t_{II,III} - t_s$ = December 1 - May 9 = 206 days

$\Delta t_E + \Delta t_L + \Delta t_{J_I} = 1.5 + 21 + 30 = 52.5$ days

$f(t) = 153.5 - t$

The integral in equation 22 is then evaluated to yield:

$$N_1 = \overline{P'(t)} \; [\exp(-K'_E \Delta t_E - K'_L \Delta t_L - K'_{J_I} \Delta t_{J_I} - K'_{J_{III}} \Delta t_{J_{III}}] \, F_{J_{II}} \tag{23}$$

in which:

$$F_{J_{II}} = (K_{J_{II}})^{-1} \left| \exp\{-K_{J_{II}}(t_{II,III} - t_s - \Delta t_E - \Delta t_L - \Delta t_{J_I} - T_E)\} - \exp\{-K_{J_{II}}(t_{II,III} - t_s - \Delta t_E - \Delta t_L - \Delta t_{J_I})\right|$$

IV. SELECTION OF PARAMETERS

Table 2 presents several of the stanzas of the first year of life history for striped bass.

We have chosen 1.5 days as an average time period for egg incubation based on the work of Mansueti (3), but it is understood that this time interval is governed under natural conditions by the existing temperature regime.

The time interval for spawning is based on data taken from the Carlson-McCann report (7), but again, the interval and the dates themselves probably depend upon the interaction of temperature and photoperiod.

The larval stage is defined here as that life span which begins with the newly hatched prolarva and ends with the qualitative acquisition of a self-deterministic swimming ability. Thus, the assignment of a time span to this life stage must be based on knowledge of growth rates and swimming ability at various lengths.

Table 3 shows growth rate data from several sources at several points in time. Data from Pearson (8), who conducted growth rate investigations in a rearing pond, indicate that striped bass attain a length of at least 1 inch at three weeks after hatching. Using growth data from natural waters (rivers and estuaries) from several states, Humphries and Cummings (16) show that striped bass are approximately 0.7 inches in length after three weeks in the larval stage.

TABLE 2

STAGES AND ASSOCIATED PARAMETERS

OF THE FIRST YEAR OF LIFE FOR STRIPED BASS

Stage	Description	Period of Life	Time of First Appearance		Passage to Next Stage		Size at time of Passage to next Stage (inches)	References and Remarks
			Earliest Date	Latest Date	Earliest Date	Latest Date		
egg	Spawn to hatch	1.5	May 9	June 15.5	May 10.5	June 17	0.134	Mansueti (3) Fertilized & water hardered
Larval	Hatch to free swimmers	21	May 10.5	June 17	May 31.5	July 8	3/4 to 1	Pearson (8), Humpries & Cummings(16)
J_I	Non-screenable	30	May 31.5	July 8	June 30.5	Aug. 7	2	Mansueti (3), Rathjen & Miller(6)
J_{II}	Screenable, migrating	116-153.5	June 30.5	Aug. 7	Dec. 1	Dec. 1	3.3	Carlson - McCann (7)
J_{III}	Screenable, over wintering	159	Dec. 1	Dec. 1	May 9 of following year		3-4	Little growth during overwintering stage

NOTES:

1. Period of Spawn = 37.5 days
2. This date coincides with the earliest date of 1st appearance of the next stage
3. This date coincides with the latest date of 1st appearance of the next stage

TABLE 3

GROWTH DATA BASED ON AVERAGE SIZES FOR VARIOUS AGES
OF LARVAL AND YOUNG STRIPED BASS

Mansueti, 1958		Pearson, 1958		Patuxert River Seine Collections		Hudson River Data Cornwall Report 1965, 1968		Hudson River Data QL&M Collections, 1971		Hudson River Data Rathjen & Miller 1955		Humphries & Cumming	
Observed Age	Ave. Total Length (mm)	Observed Age	Ave. Total Length (mm)	Estimated Age	Ave. Total Length (mm)	Estimated Age*	Ave. Total Length (mm)	Estimated Age*	Ave. Total Length (mm)	Estimated Age*	Ave. Total Length (mm)	Estimated Age	Ave. Total Length (mm)
Hatching	2.9	Hatching	3.2										
1 day	3.6	--											
1.5 days	---	1.5 days	4.4										
2 days	5.1	2 days	---										
3 days	5.6	3 days	5.2										
		4 days	5.8										
		6 days	6.0									3 wks	17 (.7")
		8 days	9.0										
		16 days	13.0 (.5")							(1955) 5 wks	26 (1")		
		3-4 wks	36.0 (1.4")										
				4 wks	42.0 (1.7")	(1968) 7 wks	23 (.9")	7 wks	38 (1.5")			7 wks	49 (1.8")
				8 wks	68.0 (2.7")	(1968) 8 wks	33 (1.3")			(1955) 8-9 wks	51 (2")		
						10-11 wks	51 (2")	11 wks	61 (2.4")			11-12 wks	51 (2")
						(1965) 19 wks	79 (3.1")						

* Age calculated from May 28 which is the mid-point in the spawning season.

Data from the Hudson suggest that growth rates for young striped bass may not be as rapid as those found in other studies, especially those rates deduced from studies in more southern latitudes or in hatchery ponds. However, data from Rathjen and Miller (6) show that striped bass in the Hudson are approximately one inch long within five weeks after hatching and, even if we assume linear growth with time, they would be somewhat over 1/2 inch long after three weeks in the larval stage.

The data are fairly consistent with respect to acknowledging the swimming ability of larval and post-larval striped bass. Larval striped bass collected in plankton nets during the Cornwall study did not exceed 1/2 inch in length and this was attributed to net avoidance by larvae of larger size.

Kerr (4) shows that striped bass as small as 3/4 inch consistently oriented themselves against a water current and were able to swim in current velocities higher than 1 ft/sec. Mansueti (3) states that two to five day old larvae about 0.2 inches long are able to swim in pursuit of live food in aquarium studies. Humphries and Cummings (17) state that larvae of this size carefully approach their prey and suddenly swim forward to capture it.

If credence is given to the literature, it is almost certain that a striped bass post-larva, after three weeks in the Hudson River, has graduated from its planktonic stage and is now a relatively self-determinative organism.

The next life stanza is designated as the non-screenable juvenile stage (J_I) and it is temporally defined by the time span running from the end of the larval stage to that time at which the juvenile attains a length of two inches. The two-inch length is the criterion which separates the non-screenable from the screenable juveniles (4).

We have assigned a value of 30 days to this time span, which allows the fish a total of 51 days from the time of hatching to achieve a screenable length.

The 30 day period has been employed in all computations to date. If the period were increased, this will increase the opportunity for entrainment, but may be off-set by the fact that at present, all early juveniles (J_I) have been made subject to entrainment. This is considered to be a conservative assumption, since it appears unlikely that the plant would have an equal effect on all, recognizing the free swimming ability at this point and the apparent desire to seek shallows and shoals.

The 3.3 inch mean length assigned to the young bass on December 1 is taken directly from the data presented in Carlson's report (7). The description of migrating for the J_{II} stage and overwintering for the J_{III} stage simply recognizes the behavior of the fish during the periods of the year associated with each of these two stages.

V. PRESENTATION OF MODEL RESULTS

This chapter discusses the application of the model and shows some preliminary results. Survival fractions and reproductive parameters employed in the model, and the resulting population estimates are presented. Justification of the parameters employed and discussion of the population results as being representative of conditions in the Hudson River today is held to Chapter VI, in which the significance of the results presented herein are discussed.

We propose to assess quantitatively the impact of a new use of the River, such as the future operation of a new power plant, on the life cycle of the striped bass. This quantitative assessment is to be done by modifying survival rates in the various stages of the fishes' development.

Establishment of Present Population Level

To determine this impact, it is first necessary to establish an existing condition of bass survival in the River. This condition is presumed to have existed in the Hudson River over the past several years, and reflects the gross influence of the environment on the striped bass and their long term adaption to this environment.

As described previously, we begin by presuming that the long term picture is one of equilibrium. This means that the specific survival rates for each stage and other factors, such as the reproductive parameters of maturity, fecundity and sex distributions, should be chosen within the known range of each for each stage of life, and in such a way that the net effect is to generate a stable population. The ability to do so may be judged as support of the reasonableness of the equilibrium condition.

As described previously, it is recognized that the current condition of striped bass in the River may more likely be one of population growth. If so, then for the purposes of this study, the presumption of equilibrium is conservative, because the impact of a given level of plant operation on a growing population, if adverse, should be less than on an existing stable population. Some quantitative estimates of plant impact on a growing population are given in the next chapter.

Note that up to this point and throughout the ensuing development, no consideration of compensation is given. Compensation recognizes that pertubations in one stage of a biological life cycle tend to be balanced by offsetting or compensating factors which arise as a result of the perturbation.

This notion is basic to population dynamics of all biological systems. At this stage, therefore, the fish life cycle model being employed to evaluate the impact of the perturbation to be imposed on the Hudson River fishery when Indian Point Unit 2 goes into operation must be considered as unquestionably conservative. Some quantitative aspects of compensation on the system under study are discussed in a later section of this testimony.

Two equations are required to define the equilibrium adult striped bass population (at start of spawning, May 9):

1. the equilibrium equation (Equation 21)
2. the total adult bass population equation (Equation 16)

They are repeated again below with emphasis on the meaning of the individual terms:

Total Adult Bass Population:

$$\sum_{i=1}^{13} N_i = \text{[Total Eggs Prod.] [Egg Survival] [Larval Survival] [Juvenile I Survival] [Juvenile II Survival] [Juvenile III Survival]} \sum_{i=1}^{13} \exp - \sum_{j=1}^{i-1} K_j \Delta t_j \quad \text{.............(24)}$$

in which:

Total eggs produced $= P'(t)\ T_E$

Egg Survival $= e^{-K_E \Delta t_E}$

Larval Survival $= e^{-K_L \Delta t_L}$

Juvenile I Survival $= e^{-K_{J_I} \Delta t_{J_I}}$

$$\text{Juvenile II Survival} = \frac{1}{K_{J_{II}} T_E} \left[e^{-K_{J_{II}}(C-T_E)} - e^{-K_{J_{II}} C} \right]$$

$$C = t_{II,III} - t_s - [\Delta t_E + \Delta T_L + \Delta T_{J_I}]$$

$$\text{Juvenile III Survival} = e^{-K_{J_{III}} \Delta t_{J_{III}}}$$

Equilibrium: 1 = [Egg Survival] [Larval Survival] [Juvenile I Survival]

[Juvenile II Survival] [Juvenile III Survival]

$$\sum_{i=1}^{13} f_{s_i} f_{m_i} F_i \left(e^{-\sum_{j=1}^{i-1} K_J \Delta t_J} \right) \quad \text{........ (25)}$$

where:

i = year class

f_{s_i} = sex ratio of i (No. of females/no. of fish)

f_{m_i} = maturity index (No. of mature females/ no. of females)

F_i = fecundity (No. of eggs spawned/mature female)

$\sum_{J=1}^{i-1} K_j \Delta t_j$ = 0

The equilibrium condition requires that a balance be reached between survivals at individual stages such that the product of all items in Equation 25 equals unity.

By using estimates for all but one of the parameters in Equation 25, the last remaining parameter can be computed to satisfy the balance. The computed value of this parameter is then checked for consistency with a known estimate.

By substituting the parameters required for use in Equation 25 into Equation 24 and knowing the total eggs produced during the spawning season, the total adult bass population may then be computed. The total egg production was computed from an analysis of the 1967 Hudson River striped bass egg survey measurements (7), and found to be 1.83×10^9 eggs produced (based on a 10% egg survival rate and a 1.5 day hatch time). The significance of the egg production estimate on total population is discussed in Chapter VI.

Estimates of survivals at equilibrium for the several phases of the striped bass life cycle are given in Table 4. Estimates of sex ratios (f_{si}) maturity indices (f_{mi}) and fecundities (F_i) for adult striped bass are given in Table 5.

Reproductive parameters generally were obtained from the literature as given under Table 5. Survivals in the early stages are generally acknowledged to be very low. Survivals in the adult stages presume the inclusion of all present impacts on the River, including exploitation by sport and commercial fishing and by existing plants.

TABLE 4

SURVIVAL RATE SELECTION

Stages	Percentage Survival Ranges	Percentage Survivals Selected for Use in Model Run #1	Run #2	Run #3
Eggs	1 to 10	1	10	10
Larvae	0.05 to 1	0.5	1	1
Juveniles				
I - non-screenable	20	20	20	20
II - screenable, migrating	40 to 60	40	50	60
III - screenable, overwintering	20 to 40	20	18.4*	40
Developing Adults				
One & Two Year Olds	30 to 99*	99*	51.8**	66.8*
Three Year Olds	30 to 90	80.1*	51.8**	30
Mature Adults				
Four to 13 Year Olds	30 to 90	80	51.8	30

* Chosen to permit the total set of survival and fertility factors to satisfy the condition of equilibrium.

**Chosen originally as 50%. Associated mortality rate, K, was then computed and rounded. This resulted in a slightly higher survival of 51.8%.

TABLE 5

SELECTED FERTILITY FACTORS

Age Group	Female Fraction*	Female Maturity**	Fecundity (Eggs/Fertile Female)***
1	.5	0	0
2	.52	0	0
3	.54	0	0
4	.56	.25	345,000
5	.58	.75	438,000
6	.6	.95	615,000
7	.62	1	752,000
8	.64	1	820,000
9	.66	1	909,000
10	.68	1	910,000
11	.7	1	964,000
12	.7	1	1,136,000
13	.7	1	908,000

* (Ref.19) Values between age group 1 and 11 were linearly interpolated from estimates of age group 1 and 11 female fractions.

** (Ref.20,21) Age groups 4 - 6 are computed estimates.

*** (Ref.18) Computed by weighted averages of individual measurements.

Discussion of the rationale employed in selecting these survivals is deferred to the next chapter.

It should be noted at this point that the three model runs referred to in Table 4 reflect arbitrary selections of variables within reasonable ranges and is not an attempt to place upper and lower bounds on the predicted populations. The reasonableness of these selections and associated results is discussed in Chapter VI in the light of existing data and the survival fractions chosen.

By selecting all parameters as indicated in Tables 4 and 5, except that for the survival of one or two stages, the survival fraction for that stage or stages could be computed. For example, in Run #2, all parameters save the survival fraction in the J_{III} stage were estimated and inserted in the equilibrium model. A J_{III} survival percentage of 18.4% was found necessary to maintain equilibrium.

This value is only slightly lower than the lower limit originally chosen for the J_{II} survival range, i.e., 20%. Use of slightly lower survivals on the larval and Juvenile II stages would have increased the Juvenile III survival into the 20 to 40% range. Similar statements apply to the other runs shown in Table 4.

The adult population (on May 9) was then computed from the assumed equilibrium survival rates. For the three population runs made, these populations were found to equal 9,417, 69,534 and 201,550 striped bass. These estimates include all fish in age groups

1 through 13. The age group distribution of these adults is shown in Tables 6, 7 and 8.

These population numbers are carried out to individuals in the computer and have not been rounded. This assists the identification of the specific "run" being reported. These population estimates appear low at first glance. Discussion of these estimates is given in detail in the following chapter.

Figure 5 is a plot of the equilibrium adult population for the set of conditions chosen for Run #3. This simply shows the ability of the model to hold a long term equilibrium.

Use of the Equilibrium Approach to Estimate Plant Impact

The previous section presented the development of existing population levels in the River, using the equilibrium approach. This section shows how the equilibrium equations are perturbed by a new influence on the River, such as the proposed plant.

In order to compute the effect of interference (withdrawal of eggs and larvae by power plants, etc.) on the adult bass population, the equilibrium survival rates in the entrainable stages were lowered by adding the plant mortality factor, fQ_p/V (see page 28) to the mortality rate, K, for each of these stages. The new one year old population was then computed from Equation 24 (with i=1). The population for each subsequent ith age group was computed by using the previous year's ith-1 age group population in accordance with Equation 12.

TABLE 6

AGE GROUP DISTRIBUTION OF ADULTS

AT BEGINNING OF SPAWNING (MAY 9)

(Equilibrium Model)

Year Class	Numbers	
1	1,455	
2	1,440	
3	1,426	
4	1,141	
5	913	
6	731	
7	585	
8	468	
9	374	
10	299	
11	240	
12	192	
13	153	
TOTAL	9,417	say 10,000

Stage	% Survival Used In Model
Eggs	1
Larvae	.5
Juveniles	
I	20
II	40
III	20
Developing Adults	
One Year Olds	99*
Two Year Olds	99*
Three Year Olds	80.1
Mature Adults	80

* to satisfy equilibrium equation

TABLE 7

AGE GROUP DISTRIBUTION OF ADULTS

AT BEGINNING OF SPAWNING (MAY 9)

(Equilibrium Model - Estimated Lower Bound)

Year Class		Numbers	
1		33,494	
2		17,363	
3		9,001	
4		4,666	
5		2,419	
6		1,254	
7		650	
8		337	
9		175	
10		91	
11		47	
12		24	
13		13	
	TOTAL	69,534	say 70,000

Stage	% Survival Used In Model
Eggs	10
Larvae	1
Juveniles	
I	20
II	50.05
III	18.39*
Developing Adults	
One Year Olds	51.8**
Two Year Olds	51.8
Three Year Olds	51.8
Mature Adults	51.8

* to satisfy equilibrium equation
**Reflects original selection of 50%, computation of associated mortality rate, K, and subsequent rounding of K.

TABLE 7

AGE GROUP DISTRIBUTION OF ADULTS

AT BEGINNING OF SPAWNING (MAY 9)

(Equilibrium Model - Estimated Lower Bound)

Year Class	Numbers
1	33,494
2	17,363
3	9,001
4	4,666
5	2,419
6	1,254
7	650
8	337
9	175
10	91
11	47
12	24
13	13
TOTAL	69,534 say 70,000

Stage	% Survival Used In Model
Eggs	10
Larvae	1
Juveniles	
I	20
II	50.05
III	18.39*
Developing Adults	
One Year Olds	51.8**
Two Year Olds	51.8
Three Year Olds	51.8
Mature Adults	51.8

* to satisfy equilibrium equation
**Reflects original selection of 50%, computation of associated mortality rate, K, and subsequent rounding of K.

TABLE 8

AGE GROUP DISTRIBUTION OF ADULTS

AT BEGINNING OF SPAWNING (MAY 9)

(Equilibrium Model)

Year Class		Numbers	
1		87,402	
2		58,401	
3		39,023	
4		11,707	
5		3,512	
6		1,054	
7		316	
8		95	
9		27	
10		9	
11		3	
12		1	
13		0	
	TOTAL	201,550	say 200,000

Stage	% Survival Used In Model
Eggs	10
Larvae	1
Juveniles	
I	20
II	60
III	40
Developing Adults	
One Year Olds	66.8*
Two Year Olds	66.8*
Three Year Olds	30
Mature Adults	30

* to satisfy equilibrium equation

ADULT STRIPED BASS POPULATION
HUDSON RIVER

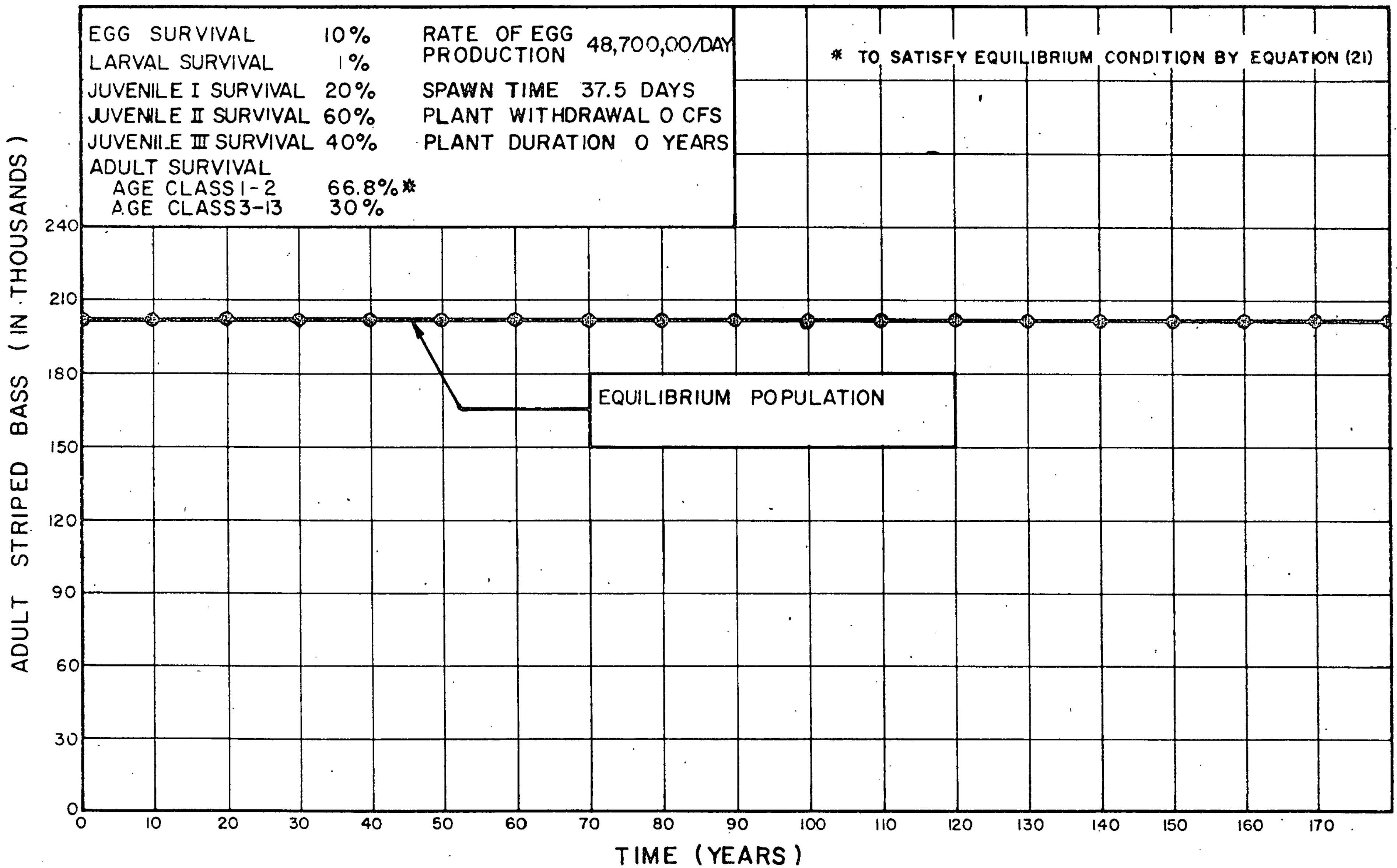


FIGURE 5

The new egg production was computed from Equation 18 using the recently computed adults. This procedure was then repeated for as many calendar years as desired. This procedure is illustrated schematically in Figure 6.

Effect of Indian Point Operation

In this present testimony, Indian Point Unit 2 is considered to operate for one year only. This represents the immediate future. Application is being made to operate this unit at this time for the duration of the full power NEPA hearings. The foregoing population model is used below to show that operation of the plant during this period can be expected to have a very small effect on the long term Hudson River striped bass population.

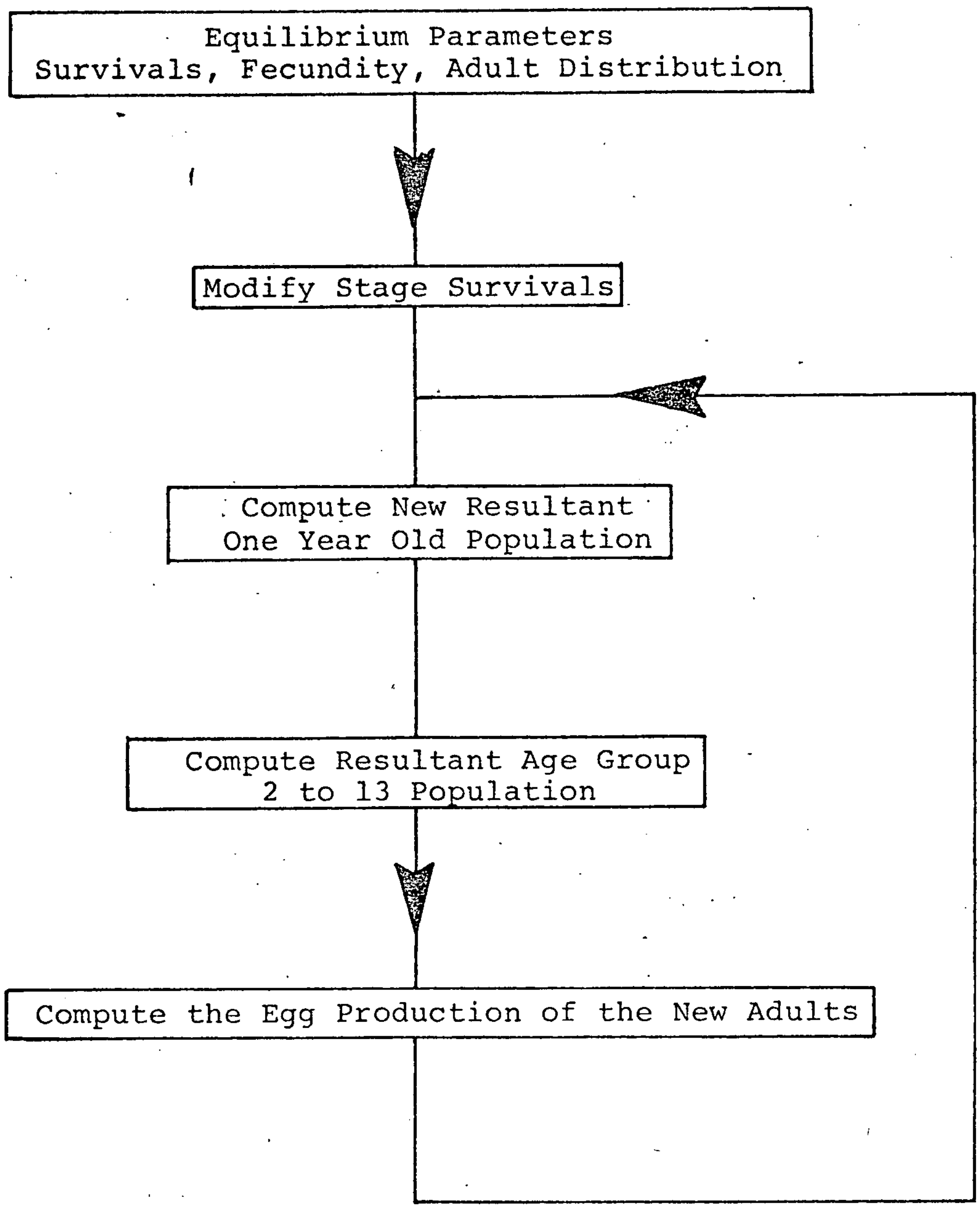
The plant is presumed to start operating on May 9 of this year and to continue operating for one full year. If the plant were actually to begin operation a month or so later, this would reduce the number of eggs and larvae entrained this year and would have some reduced effect on the number of juveniles entrained if operations ceased before May 9, 1973. However, since we are assuming one full year of operation, it should make virtually no difference in the final population estimates when the plant actually commences operation.

Figure 7 shows how one year's operation of Indian Point Units 1 and 2 at design flow (2607 cfs) is expected to influence each

FIGURE 6

COMPUTATION OF ADULT STRIPED BASS POPULATION

WHEN EQUILIBRIUM IS DISTURBED



ADULT STRIPED BASS POPULATION HUDSON RIVER

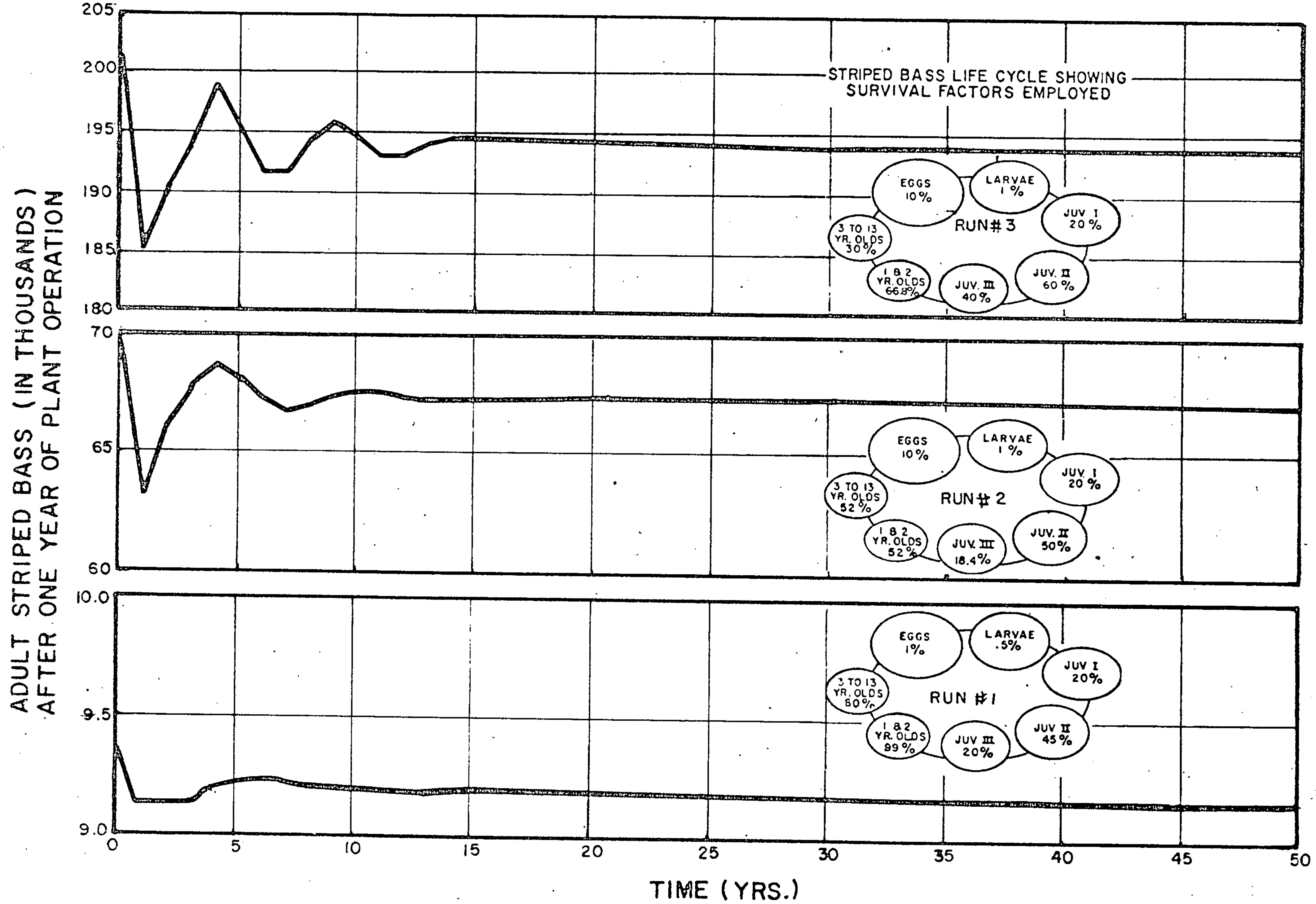


FIGURE 7

of the three equilibrium adult striped population levels presented previously. These results represent the assumed case of 100% mortality of all eggs, larvae and juveniles entrained in the plant flow and reflects all of the other conservative assumptions made in the development of this present model including the assumption of no compensation.

Note that the greatest reduction occurs in the early years, that the population recovers after operations cease, and eventually levels out to a new and slightly lower long term equilibrium population. The reasons for this behavior are described below.

Time in Figure 7 is measured from the point at which the first year's operations begin and is assumed to be May 9, 1972.

During the first year of survival reduction, the number of young of the year survivors is reduced since the survival through the egg, larval and Juvenile I stages has been reduced. This results in a lower age group I production the following May 9 and, therefore, a lesser total population at the end of the first year. Egg production will not be affected for 4 years since females are not mature until they reach age group IV.

During the second year, when the plant is no longer operating and survival reduction is removed, the original (Tables 6, 7 and 8) age group I population is again generated, since the egg production has not yet been affected. Therefore, the total population is greater than for the first year. This is so because the difference in the age II population between the zeroth (before plant operation) and second years is less than the difference in the age I population between the zeroth and first years.

During the third and fourth years, the original age group I population is generated and a further increase in population begins. Egg production has yet to be affected.

During the fifth year, the egg production is affected since the reduced age group I yield during the year of survival reduction now appears in age groups IV. This will result in lower total egg production, thereby yielding lower age group I yields for this and all subsequent years. This <u>net</u> lower production also results in a <u>net</u> lower total population which theoretically will stabilize after at least 13 years but practically is shown in Figure 7 to stabilize at about year 10.

Note that this entire analysis ignores any compensation, whereas in reality, compensation of the theoretical reduction in recruitment at the end of the first year may occur in either the later juvenile stages (J_{II}, J_{III}) or in increased survival or fecundity of that year class in later years.

Note also that the one year of operation may be likened to normal random variation in this biological system. The induced mortality rate, given by fQ_p/V, represents about a 1 to 5% increase in the mortality rates of the eggs, larvae and very early juveniles, the entrained stages.

The reduction of the system's population due to these increased mortalities varies during the first several years but eventually stabilizes to a long term reduction on the order of 3%.

A more realistic view of the situation is to recognize that random fluctuations occur in both directions and are due to changes in artificial as well as natural factors. The very minor impact of the one year of operation may well be off set by improvement (from the naturalist's viewpoint) in other aspects of man's use of the River. This is particularly true when one considers that such improvements are usually long term; e.g., new and upgraded sewage and industrial waste treatment plants by comparison to the single year of operation being considered here.

The Influence of Compensation

Pursuit of the notion of random variation in a biological system leads to the conclusion that compensation must, rather than may, exist in a biological system such as the one under consideration here.

Using the Run #2 set of equilibrium conditions, Figure 8 has been prepared to illustrate the effect on the total adult bass population of randomly varying the survival of juvenile II's about their equilibrium survival of 50%. For the random numbers chosen during this particular run, an increasing unbounded population appears to result. However, the very notion of equilibrium in a real system is only in a long term sense. Yearly fluctuations about a mean are always expected, but a long term

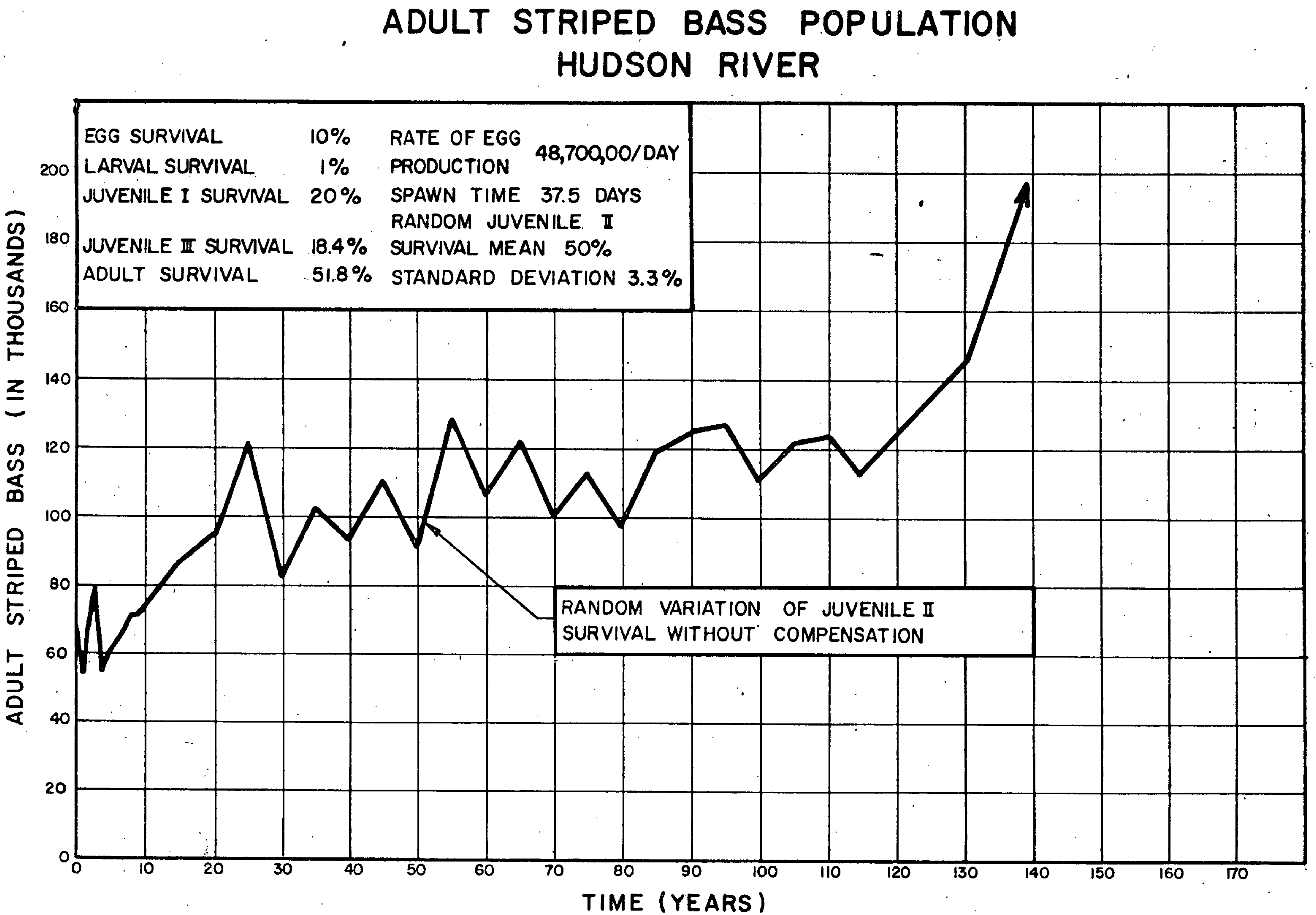

ADULT STRIPED BASS POPULATION
HUDSON RIVER
EGG SURVIVAL 10%
LARVAL SURVIVAL 1%
JUVENILE I SURVIVAL 20%
JUVENILE III SURVIVAL 18.4%
ADULT SURVIVAL 51.8%
RATE OF EGG PRODUCTION 48,700,00/DAY
SPAWN TIME 37.5 DAYS
RANDOM JUVENILE II SURVIVAL MEAN 50%
STANDARD DEVIATION 3.3%
RANDOM VARIATION OF JUVENILE II SURVIVAL WITHOUT COMPENSATION
ADULT STRIPED BASS (IN THOUSANDS)
0
20
40
60
80
100
120
140
160
180
200
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
TIME (YEARS)

FIGURE 8

equilibrium condition can still occur.

A second inconsistency between results generated by the conceptual model and physical reality is the fact that any sustained perturbation, however small, in the deterministic equilibrium model will cause the population to grow without bound if such perturbation is positive (e.g., an increased survival rate in any state) or to decrease to extinction if the perturbation is negative (reduced survival rate). The number of years to move in either direction, of course, depends on the magnitude of the perturbation, but the fact still remains that any sustained perturbation, rather than moving the system to a new finite equilibrium level, will move it exorably to either unbounded growth or extinction, neither of which is consistent with physical reality.

These inconsistencies with physical reality can be accounted for by the fact that in the conceptual framework presented so far, there has been no provision for the various compensatory mechanisms that appear in natural populations. These mechanisms are varied in form, but they often can be explained in terms of the availability of a suitable food supply. An explanation of compensation in the size of a fish population in terms of food supply is given below.

An ever-increasing population is eventually faced with a decreasing food supply. Decreasing food supplies cause a decrease in the growth rate. With this is connected a later onset of maturity, and frequently a decrease in the fecundity of younger fish of the same size. In this way, replacement of the stock is slower when the feeding conditions are impoverished.

Among many groups of fishes, such as the perch, cods, and sunfish, the larger individuals feed upon the smaller ones of the same species (21). A large parental population, which produces an initially large number of offspring will also, by virtue of the large numbers present, exert heavy cannibalistic pressure upon the young (23).

Other self-regulatory mechanisms related to food supply and population density include the reduction of fat content and a concomitant reduction in fecundity (fat reserves provide much of the material for egg production), reduction in larval survival during the first stages of active feeding, and an increase in the size range of the eggs along with an increase in the amplitude of variability of the size of fishes at the same age.

This last mechanism ensures that at least a certain complement of the year class (the larger individuals) will survive. If they were all the same size, the competition for food may be intense enough to essentially eliminate the spawning potential for that year class.

The converse of these mechanisms would occur in the face of a declining population and an increasing food supply.

A simple compensation mechanism has been introduced in the Juvenile II stage to illustrate how recognition of compensation in the system will eliminate the inconsistencies previously the same size. In this way, replacement of the stock is slower when the feeding conditions are impoverished.

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The converse of these mechanisms would occur in the face of a declining population and an increasing food supply.

A simple compensation mechanism has been introduced in the Juvenile II stage to illustrate how recognition of compensation in the system will eliminate the inconsistencies previously noted when the equilibrium model is used to simulate known behavior. This is explained below.

Since eggs after fertilization are not in competition for space or food, it is unlikely that their survival rate is directly affected. In their early stages, larvae now nourished through the yolk-sac for, and at least during this period, probably do not enter into much competition. On the other hand, juveniles do compete for space and food. Hence, it is possible that the reduced recruitment to these stages enhances their chances of survival.

For illustrative purposes, we have chosen only the Juvenile II stage for compensation to take place. The specific perturbation being compensated is the entrainment of eggs, larvae and non-screenable juveniles.

The compensation mechanism chosen states that the unit mortality rate in the J_{II} stage (KJ_{II}, page 38) changes as the population of J_I survivors departs from its equilibrium level, and that the new unit rate is proportional to the equilibrium rate as follows:

$$KJII_p = KJII_E \left(\frac{NJI_p}{NJI_E} \right) \quad \ldots\ldots\ldots\ldots\ldots (26)$$

in which:

NJI_p, NJI_E = perturbated and equilibrium surviving JI population levels, respectively.

$KJII_p$, $KJII_E$ = unit mortality rates, J_{II} stage, at the perturbated and equilibrium J_{II} population levels, respectively.

Equation 26 simply recognizes that as the surviving population in the former stage (JI) increases above the equilibrium level, mortality in the next stage (J_{II}) increases to offset this, and as the population decreases below equilibrium, mortality decreases, again offsetting the original perturbation.

By reference to the life cycle model development in Chapter III, the ratio of surviving non-screenable juveniles, for the case in which plant operation is considered to be the perturbation, is written:

$$\frac{N_{JI_p}}{N_{JI_E}} = \frac{\overline{P'_p(t)}}{\overline{P'_E(t)}} \quad e^{-w}$$

in which:

$\overline{P'_p(t)}$ = rate of egg production in any year due to the perturbation by the plant

$\overline{P'_E(t)}$ = rate of egg production at equilibrium

$w = f_E \frac{Q_p}{V} \Delta t_E + f_L \frac{Q_p}{V} \Delta t_L + f_{J_I} \frac{Q_p}{V} \Delta t_{J_I}$

(these parameters are all defined on pages 18 through 25)

The fraction of J_I survivors that make it through the J_{II} stage; i.e., become J_{II} survivors is given as:

$$\frac{N_{JII_p}}{N_{JI_p}} = \exp\left[-K_{JII_p} \Delta t_{J_{II}}\right] \qquad \ldots\ldots\ldots (27)$$

Substitution of Equation 26 into Equation 27 yields:

$$\frac{N_{JII_p}}{N_{JI_p}} = \exp\left[-K_{JII_E} \Delta t_{JII}\right]^{\left(\frac{N_{JI_p}}{N_{JI_E}}\right)} \qquad \ldots\ldots\ldots (28)$$

To illustrate the effect numerically, assume that a plant operation causes, in the original non-screenable juvenile equilibrium population, a net reduction after a given number of years of 20%. The ratio, $(N_{J_{I_p}}/N_{J_{I_E}})$ in Equation 28 is therefore 0.8. Presume an original equilibrium survival fraction in the next stage (J_{II}) of 50%. The term, exp $[-K_{J_{II_E}} \Delta t_{J_{II}}]$ therefore is 0.5. The new survival fraction in the J_{II} stage becomes:

$$\frac{N_{J_{II_p}}}{N_{J_{I_p}}} = (0.5)^{0.8} = 0.57$$

Thus, for the perturbed case in this example, the survival in the J_{II} stage increases over its original level of 50% to 57%, partially offsetting the 20% reduction in the previous stage. The eventual net result is a reduction in the computed impact of plant operation on the River's total adult population .

Similarly, if early stage survival rates were increased by say improved waste treatment practice, competition in the Juvenile II stage would increase and tendency of the population to grow would be partially offset by this phenomenon.

Mathematically, the exponent, $(N_{J_{I_p}}/N_{J_{I_E}})$ in Equation 28 would be greater than unity due to the improved environmental conditions, and the survival fraction, $N_{J_{II_p}}/N_{J_{I_p}}$, in Equation 28 would be less than its original equilibrium counterpart (exp $(-K_{J_{II_E}} \Delta t_{J_{II}})$).

Introduction of this mechanism or similar mechanisms to the life cycle model will prevent unbounded growth or extinction when the system is perturbed continuously; rather it will force the system to a new equilibrium level. These different responses of uncompensated and compensated systems to sustained pertubations are described as follows.

Before introducing compensation, we were working with first order kinetics throughout each stage. Thus, the system was entirely linear, and involved feedback (production of a new egg complement each year to keep the system going). Sustained perturbation of such systems from an equilibrium condition will always result in extinction or unbounded growth, depending on the direction of the perturbation.

Introduction of compensation, however, makes the system non-linear, since the compensation rate depends on population level (density dependence). Sustained perturbations of such non-linear feedback systems will not result in extinction or unbounded growth, but rather in the relocation of the equilibrium position.

Finally, Figure 9 shows the effect of compensation on random fluctuations in Juvenile I survivals. Over a span of 180 years, compensation continually redirects a population to its long term equilibrium population when random environmental factors alter the population of earlier stages (number of Juvenile I survivors).

Comparison of this result to that shown in Figure 8 is excellent support for the position that compensation is not a question of "perhaps it occurs," but rather "it must occur."

ADULT STRIPED BASS POPULATION
HUDSON RIVER

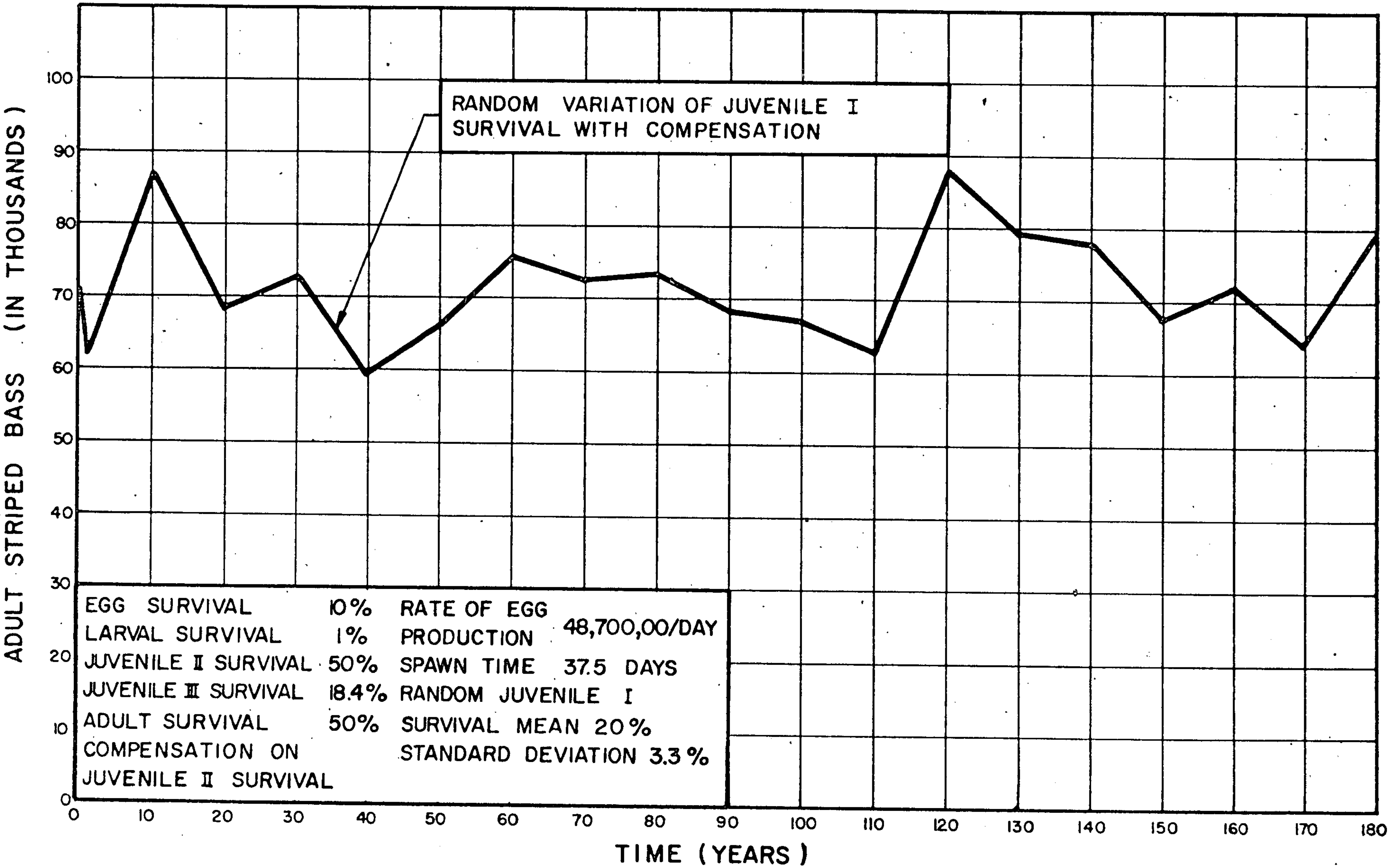


FIGURE 9

ADULT STRIPED BASS POPULATION
HUDSON RIVER

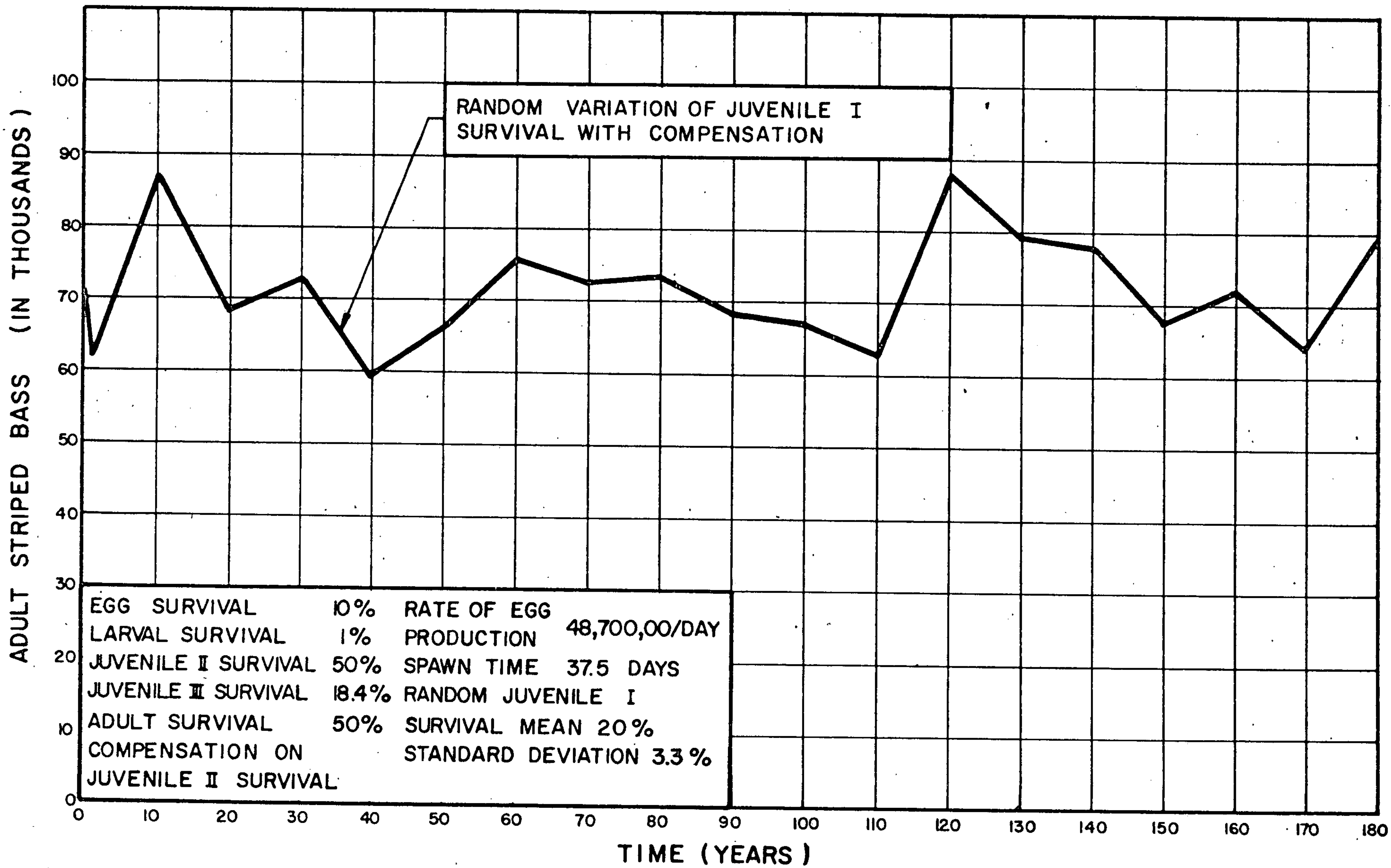


FIGURE 9

VI. INTERPRETATION OF RESULTS

This chapter discusses the sensitivity of the equilibrium model and summarizes the potential impact of the generating station at Indian Point. Findings and conclusions are summarized in Chapter VII.

Sensitivity of the Equilibrium Model

The results of the previous chapters indicate that the life cycle model, using values for survival and reproductivity parameters that fall within reasonable limits for each, will yield an equilibrium or steady state population for striped bass in the River. Furthermore, results consistent with known behavior of perturbed biological systems can be obtained when at least one stage of the cycle is permitted to compensate impact on itself or on other stages.

The magnitude of parameters used (annual egg complement, survival rates, etc.) will define the equilibrium population and use of different parameter values will yield different equilibrium populations. However, the range of parameter variation is limited and the model inherently off-sets changes in one direction by changes in the reverse, if equilibrium is to be maintained.

The three runs chosen largely reflect lack of precise knowledge of the actual survival rates for the various stages of striped bass development in the Hudson River.

Run 1 (population of roughly 10,000 adults) is considered to be too small to represent a realistic present case, in the light of information on commercial fishing, presented in reference 11.

Early stage mortality is known to be high in many estuarine species. Pearcy (22) estimates an egg survival of 16% for winter flounder in the Mystic River estuary, followed by estimates of combined survival of 0.007% to 0.018% for the larvae and juveniles through age 22.4 months.

Although these apply to another species, the values are of the same order as those chosen for the striped bass in this study. For example, egg mortality in Runs 2 and 3 was 10%. Combined larval through age group I mortality, which encompasses an average period of 23.6 months is as follows:

	Larval Through Age Group I Survival Fraction					
Run No.	Larvae	J_I	J_{II}	J_{III}	Age I	Combined
1	0.005	0.2	0.45	0.2	0.99	0.00009
2	0.01	0.2	0.5	0.18	0.5	0.00009
3	0.01	0.2	0.6	0.4	0.67	0.00032

Thus, the combined 23.6 month early stage survival varies between 0.009% and 0.032%, by comparison to the range given by Pearcy.

Preliminary review of the Cornwall data (7) suggest that overall survivals of this order are supportable for striped bass in the Hudson River.

The adult stage mortalities can also range over wide limits. Low survival beyond age 3 are considered to represent significant exploitation by sport and commercial fishing. The rationale used in selecting the adult survivals for Runs 1, 2 and 3 follows.

McFadden (23) estimates representative mean behavior to be 50% for all age groups. This estimate has been employed in Run 2, which could be considered to represent a possible intermediate population level.

The logic of possible equal survivals is that age classes 1 and 2 are more immature and vulnerable to natural factors than subsequent age classes and this additional vulnerability is of the same order of magnitude as exploitation in subsequent age groups.

Run #3 may be considered to represent a relatively high adult population within the limits of the selected survival and reproductivity parameters ranges, and the observed Cornwall egg production (7). A relatively low age 3 and beyond adult survival of 30% was chosen. This is considered to be representative of man's impact through commercial and sport fishing, since natural survival of this species beyond age 3 is judged to be higher, due to the absence of predators. The associated age group I and II survival of 66.8% was required to maintain the system at equilibrium.

Run #1 may be considered to represent an extremely low population estimate. This estimate was the result of balancing age group I and II survivals against age group 3-13 survivals with the objective of obtaining the smallest total equilibrium adult population. A combination of 99% one and two year old survival and 80% survival for the remaining age groups yielded the minimum. In the light of the present estimates of commercial catch, it is difficult to justify this lower population and it should be considered simply as representing a extreme lower limit of the population. Clearly the 99% survival in age groups I and II represents an unachievable **upper** limit of survival.

The following several paragraphs are meant to describe how the model responds to changing parameter values. With reference to Equation 24 and 25, the set of parameters appearing in Equation 25 but not included in Equation 24 is the fertility product, $fs_i \cdot fm_i \cdot F_i$, for each age group. Assume for the moment that these estimates are accurate and focus on the effect changing survival rates may have on the total population (Equation 24).

If changes in the survival's are restricted to the 0th year life stages only (eggs through J_{III}), then, to satisfy Equation 25, since these survivals all appear as products, a change in one direction in one stage must be offset by an equivalent change in the opposite direction.

For example, if the product of the egg and larvae survival fractions is halved, then the products of the three juvenile fractions must be doubled to satisfy equilibrium, if no changes are to be made in the adult terms. Inspection of Equation 24 shows, as should be expected, that this procedure will result in no change whatsoever in the adult population.

Changes, of course, can be effected in the adult population by changing the mortality rate K_i of any given age group. Such changes will also have to be offset by changes in the opposite direction of other stages, either adult or early, mortality rates, but in this case the actual population may change. Changes are not major, however, because the equilibrium condition forces bounds on the system.

Similar statements can be made even if changes in the fertility factors are included. An example of the range of adult populations that can be maintained at equilibrium is shown in Figure 10. The fecundity values given in Table 5 were each steadily decreased as shown in Figure 10, with offsetting changes being made in the Run #2 survivals of both adult and early stages.

Average fecundity over the total age group is on the order of 600,000 eggs per female, so the 300,000 decrease represents an almost 50% reduction in fecundity. An adult population change from 70,000 to 150,000 resulted due to the survival changes necessitated to maintain equilibrium. In other words, survivals of each age group of adults was increased to offset the decreasing fecundity, and, as a result, adult population also increased.

Further inspection of Equations 24 and 25 shows that the population estimate is linearly dependent on the egg production,

EFFECT OF REDUCTION IN FECUNDITY OF MATURE FEMALES ON THE HUDSON RIVER ADULT STRIPED BASS POPULATION

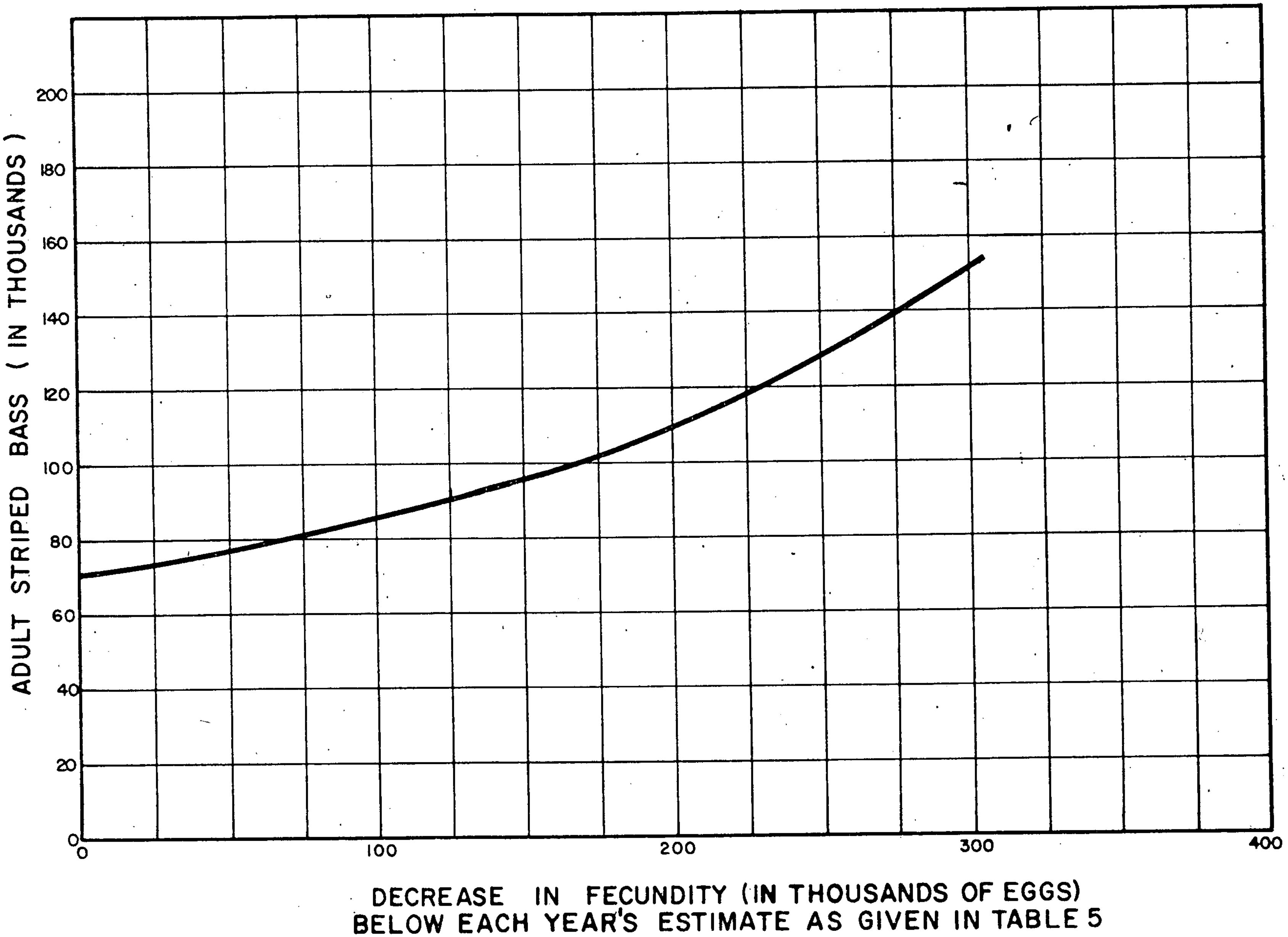


FIGURE 10

whereas this parameter (egg production) does not appear in the equilibrium equation.

Thus, it becomes clear that the equilibrium condition, rather than controlling the population estimate, really is controlling the unit population estimate, i.e., the total adult population per number of eggs produced.

This is clearly shown in Figure 11. Equilibrium adult populations were computed from Equations 24 and 25, thus using the Run #2 set of survival and fertility parameters. Period of spawn was 37.5 days and the egg production rate in Figure 10 refers to the average rate over this period. Adult population is seen to increase linearly with egg production rate, since all other parameters are fixed.

The foregoing show clearly that the population values given by Runs 1, 2 and 3 represent some of the possible equilibrium populations that could exist in the River. It is certainly possible that higher populations may actually exist, particularly where it is recognized how strongly these population estimates depend on the yearly egg complement.

It is not the purpose of this study, however, to estimate the actual population of striped bass in the Hudson River, but rather, to estimate the possible percentage charge in this population that may occur in the presence of plant operation. The 5 year Lower Hudson River Ecological Study, to which Con Ed has committed, has, as one of its objectives, the determination of absolute population levels.

ADULT STRIPED BASS vs EGG PRODUCTION RATE

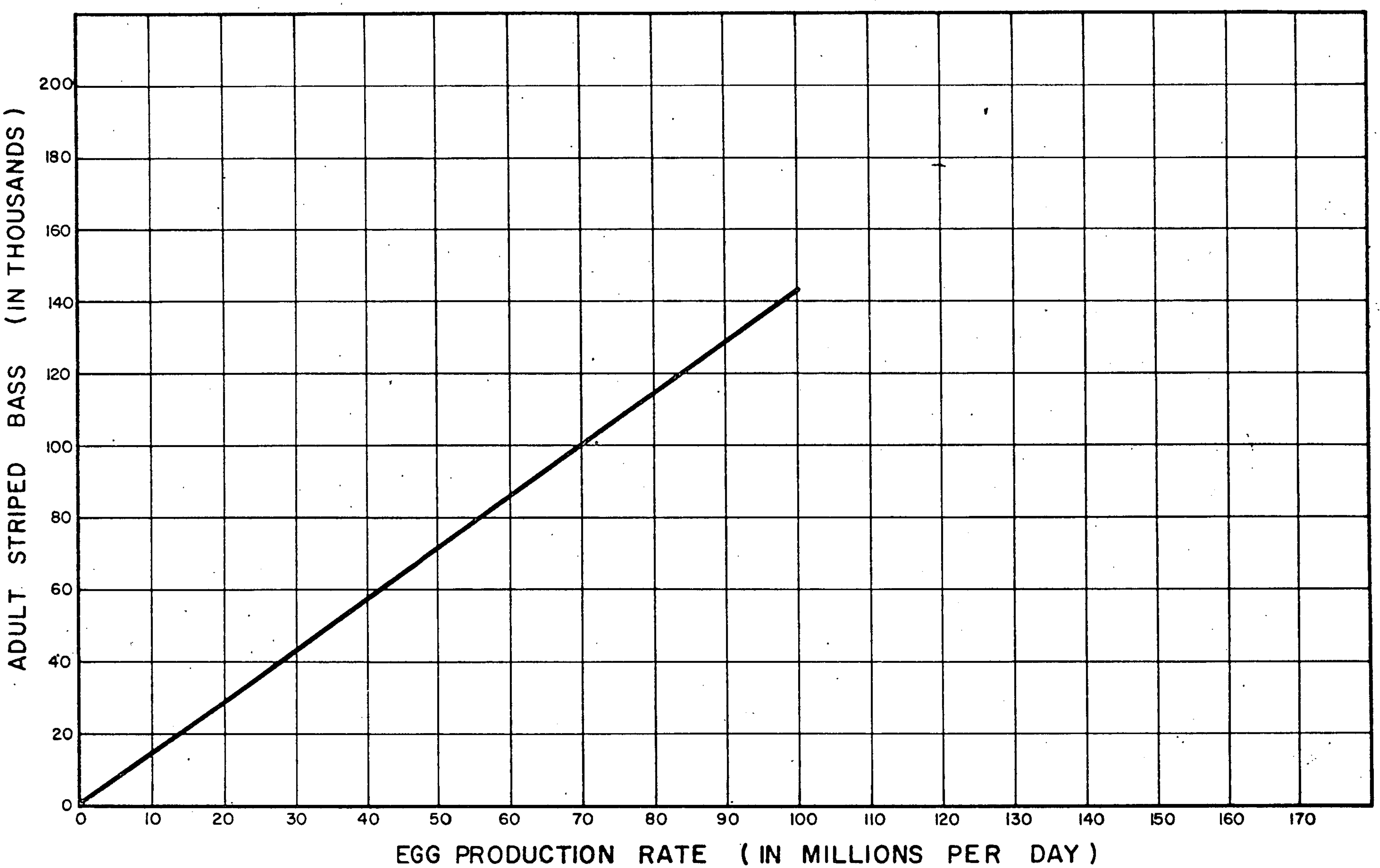


FIGURE 11

Impact of the Indian Point Plant

Figure 7 (after page 44) showed the impact without compensation of one year's operation of Indian Point Units 1 and 2 in the total adult fish population for each of the three "present day" equilibrium population levels considered. The discussion of this figure in Chapter V showed clearly that the population would oscillate in a damped manner for about 10 years before stabilizing a new equilibrium position.

The results in Figure 7 assume that the plant design flow is passing continuously through both units during the entire period of entrainment, that the entrainable fish have no ability to avoid the plant, and that all entrained individuals, whether eggs, larvae or non-screenable juveniles, are destroyed by this passage.

These entrainment assumptions result in the maximum entrainment loss at the plant. In actuality, it is quite possible that the entrainment loss may be significantly less for the following reasons:

1. Studies, some of which were referred to in Chapter I, of this testimony, show that 100% mortality does not necessarily always apply. Actual mortality is a function of many factors, and is difficult to predict without field studies at the plant in question. Such studies are planned this year at Indian Point.

2. Beyond about one week of life, the larvae begin to have some ability to resist a current and to move about of their own accord. Secondly, the post larvae and early juveniles are known to seek the bottom as well as shallows and shoals. These facts suggest it is highly unlikely that the fish in these stages, as they near the general vicinity of Indian Point, are as potentially subject to entrainment as they are assumed to be in the model.

3. Two unit plant design flow is not necessarily in operation during the entire period of potential entrainment.

Runs were therefore made to evaluate the impact on the system for various percentages of this maximum entrainment parameter (Qp/V). These results are shown in Figures 12 and 13.

Figure 12 shows the resulting new long term equilibrium populations for the various sets of survivals studied and varying percentages of maximum entrainment. The value is designated as occurring 50 years after the one year of operation begins, but, as shown in Figure 7, actually appears after 10 years of minor oscillations about this value.

Figure 13 converts the results of Figure 12 to percentage reduction of the "present day" equilibrium population level.

EFFECT OF ONE YEAR'S OPERATION OF INDIAN POINT UNITS 1 & 2 ON HUDSON RIVER STRIPED BASS POPULATION

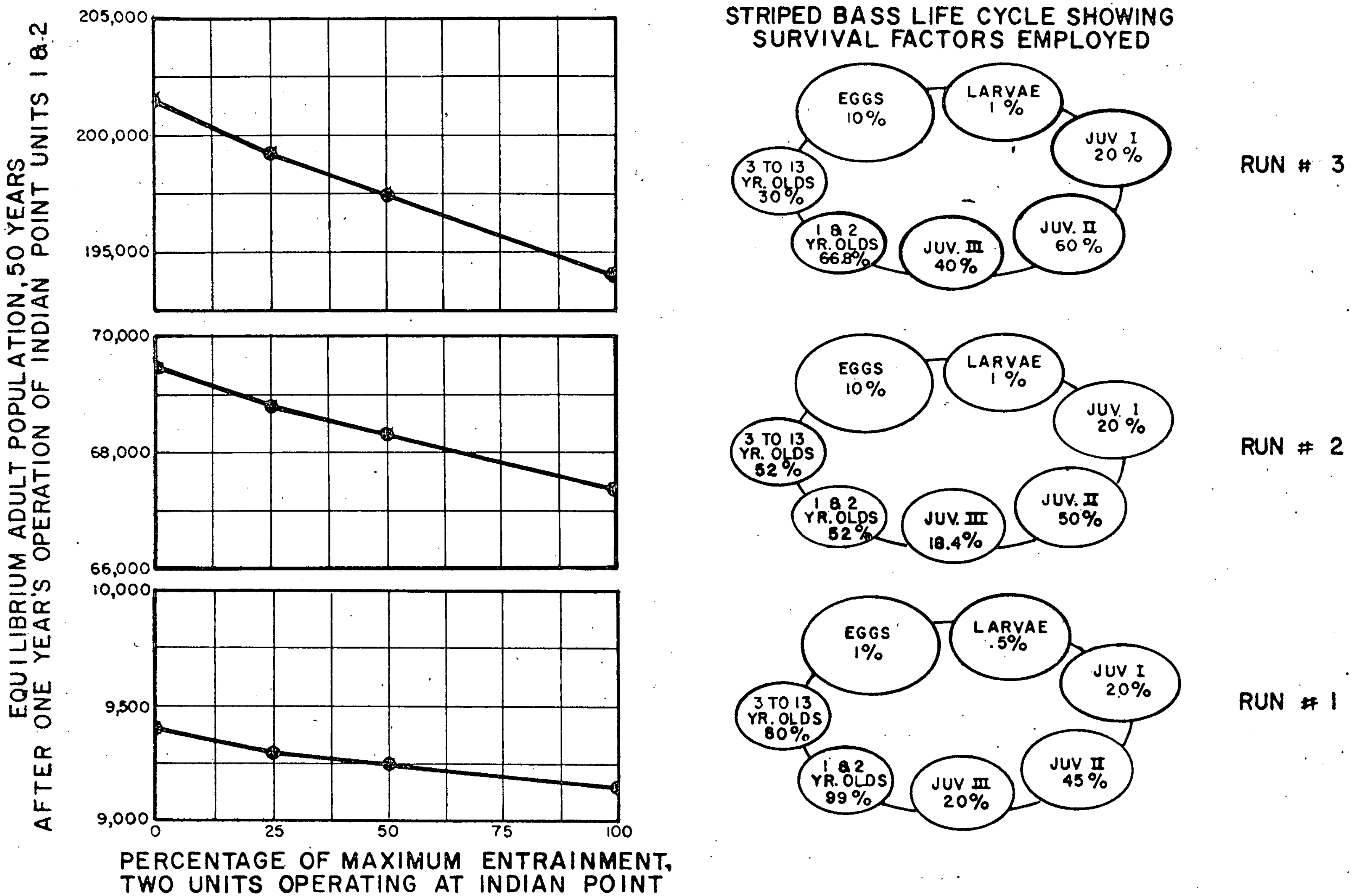
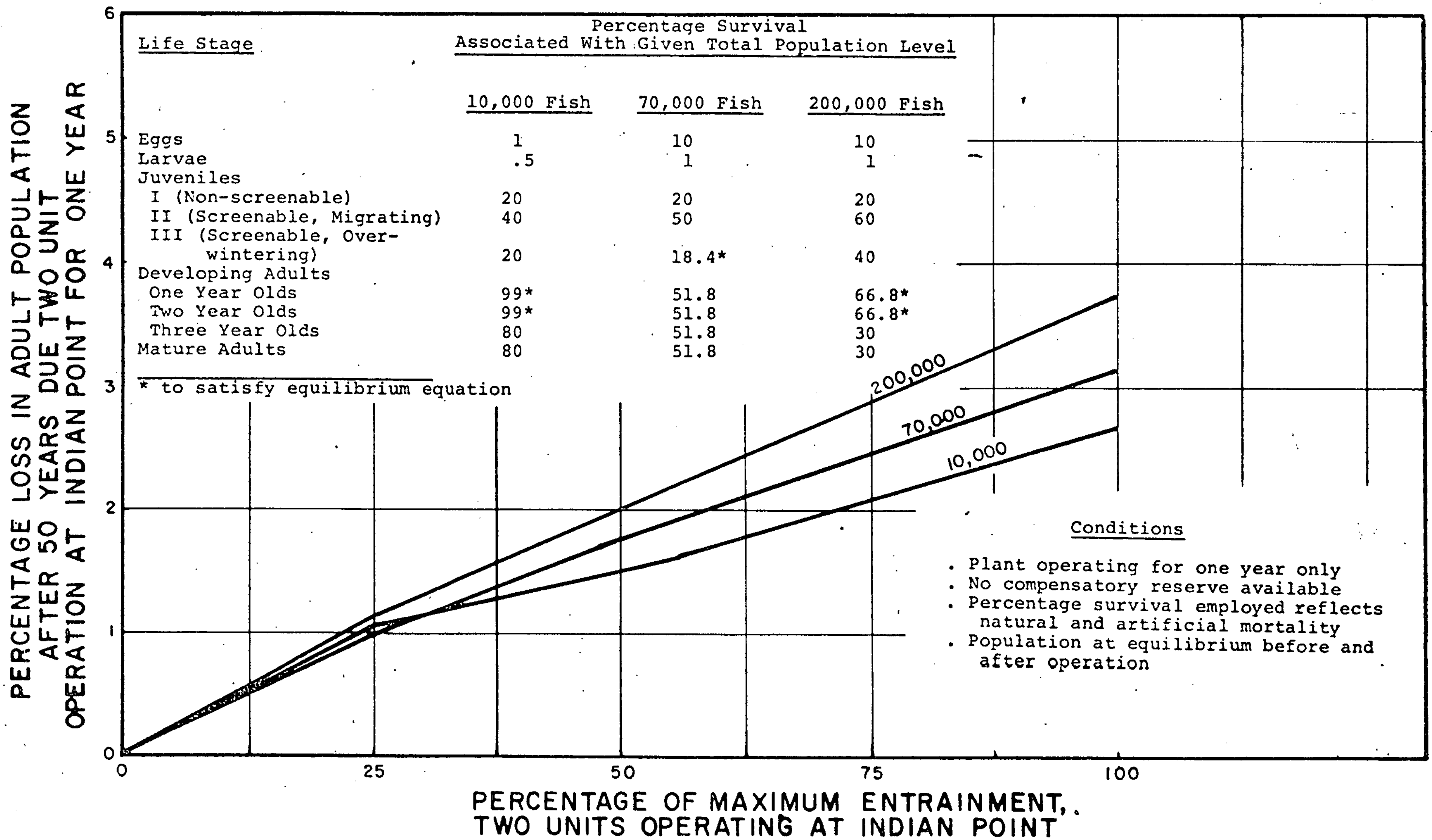


FIGURE 12

EFFECT OF ONE YEAR'S OPERATION OF INDIAN POINT UNITS 1 & 2 ON PERCENTAGE REDUCTION IN HUDSON RIVER STRIPED BASS POPULATION



Life Stage	Percentage Survival Associated With Given Total Population Level: 10,000 Fish	70,000 Fish	200,000 Fish
Eggs	1	10	10
Larvae	.5	1	1
Juveniles			
I (Non-screenable)	20	20	20
II (Screenable, Migrating)	40	50	60
III (Screenable, Over-wintering)	20	18.4*	40
Developing Adults			
One Year Olds	99*	51.8	66.8*
Two Year Olds	99*	51.8	66.8*
Three Year Olds	80	51.8	30
Mature Adults	80	51.8	30

* to satisfy equilibrium equation

Conditions

- Plant operating for one year only
- No compensatory reserve available
- Percentage survival employed reflects natural and artificial mortality
- Population at equilibrium before and after operation

FIGURE 13

The reason for this unusual "hump" in the 10,000 level curve at 25% of maximum entrainment is not yet clear but is not considered important.

Figure 13 shows clearly that one year's operation at Indian Point will have a very minor impact on the River's striped bass population. Maximum effect is estimated to be less than 4%. As discussed previously on page 47 , this one year's perturbation can be expected to be dwarfed by other natural and artificial perturbations on the system that occur every year.

This very minor impact results from the fact that the one year of operation is virtually lost when one recognizes that the total population at any given year reflects recruitment of 13 different year classes.

Additional considerations that further minimize the effect shown in Figure 12 and 13 are as follows:

1. Compensation has not been included. For short term operation, such as that for one year, introduction of the simple compensation model described in Chapter V to only one stage will drive the system back to its original equilibrium position after the short term perturbation is lifted.

2. Indian Point Unit 1 operation has been included. Actually, since this plant was operating during the period Cornwall egg data were collected, it should

be considered as part of the "present day" equilibrium conditions against which the impact of Unit 2 operation alone should be considered.

Another view of the extremely minimal impact that the one year's operation will have can be obtained by considering the joint effect a small reduction in fishing and a single year's operation at Indian Point will have on the population.

This is shown in Figure 14. Another equilibrium run, resulting in a "present day" population of 25,000 fish, is perturbated by reducing fishing by roughly 13%. This 13% fishing mortality is equivalent to an increase in survival fraction of 0.6 to 0.64 for age groups 3 through 13.

When this growth perturbation is imposed, the population increases, and since no compensation mechanism has been introduced, grows without bound. Introduction of plant operation for one year shows an initial decrease, as expected, followed by unbounded growth parallel to, and about 5% lower than the case for no plant operation. Growth continues to occur, of course, because the fishing perturbation is sustained, whereas the plant operation is short term.

This result not only shows the minimal impact of one year's operation of the plant, but again clearly demonstrates the extreme conservatism of the model when compensation is not

ADULT STRIPED BASS POPULATION
HUDSON RIVER

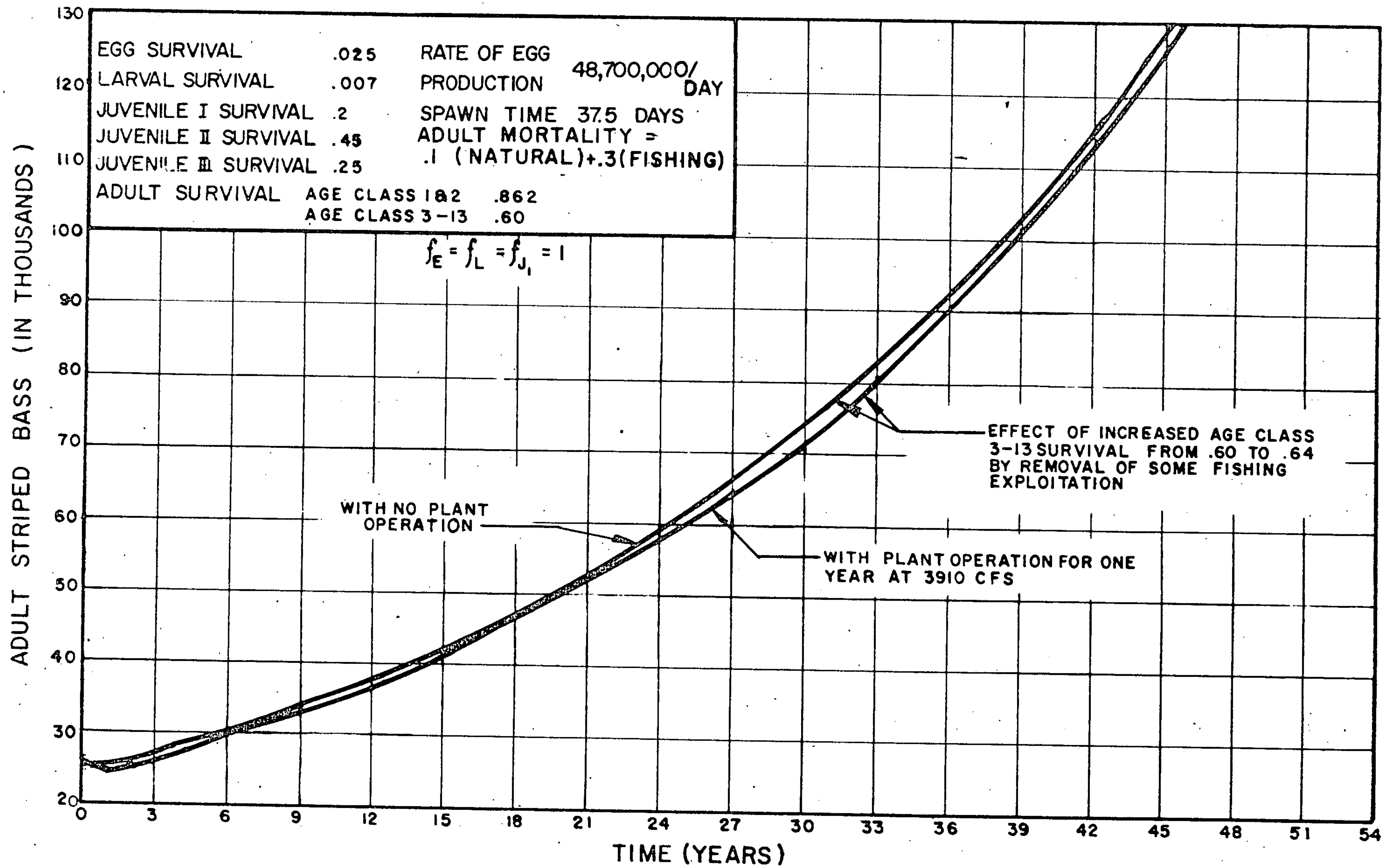


FIGURE 14

included. It is totally unrealistic to assume a 13% reduction in fishing will cause the Hudson River striped bass population to grow without bound. Similarly, it is unquestionably conservative to consider the impact of Indian Point operation on this population without including the notion of compensation.

VII. FINDINGS AND CONCLUSIONS

The foregoing analyses have presented a population model for striped bass in the Hudson River, and a conservative estimate of the impact that can be expected on that population by entrainment of eggs, larvae and early juveniles due to operation of Indian Point Units 1 and 2 during the coming year.

Results for one year's two unit full flow operation at Indian Point included:

1. Even assuming no compensatory mechanisms, very minor percentage reductions in total adult Hudson River striped bass population. These are given below for the ranges studies:

Percentage of Maximum Entrainment Loss At Indian Point Units 1 & 2	Percentage Reduction in Adult Population For		
	10,000 Fish	70,000 Fish	200,000 Fish
50	1.5	1.7	2.0
100	2.6	3.1	3.7

   Populations stabilized at these reduced levels after oscillating for about 10 years in a damped fashion about these levels.

2. No long term change in the population where a compensation mechanism is applied to one juvenile stage.

Several possibly very conservative assumptions have been employed throughout this study. Some of these are:

1. All life stages at any point in the reach between Croton Point and Coxsackie 52.5 days after spawning are subject to entrainment by the plant.

2. These life stages have no ability of their own to avoid the plant.

3. All entrained organisms are killed.

4. Plant flow is always the full design flow.

5. Compensation has not been employed in numerical estimates of impact.

Consideration of these assumptions and the nature of the model suggest the following program.

1. Use the model and subsequent refinements in guiding the 5 year Lower Hudson River Ecological Study to which Con Ed has committed.

   Particular focus should be directed toward answering questions posed by assumptions required by the model for lack of information, such as those listed above in items 1, 2, 3 and 5, and described in more detail below.

2. Determine the behavior of the early stages, with particular emphasis on the nature of their movement as they become less and less subject to River currents. We need to know whether they can avoid intake currents, and more so, whether they will avoid these currents.

3. Determine the actual concentration of organisms entrained by the plant intake, by comparison to the concentration of organisms throughout the area. In addition to sampling and measurement, this effort should include hydraulic analysis, including flow nets and possible use of the hydraulic model to determine intake flow patterns.

4. Attention should be directed toward the reported vertical diurnal movements of the young striped bass, and show this might be coupled with the intake flow patterns to compute entrainment.

5. Investigation of actual larval and juvenile damage upon entrainment. It is understood that NYU is embarking on this study in the near future.

6. Establishment of survival and fertility factors for Hudson River striped bass. This is planned as part of the 5 year program.

7. Continuation of investigation of fish protection devices, including air curtains, a method which may provide protection against entrainment as well as impingement.

The foregoing are some specific areas in which relatively broad assumptions have been made in this and other model studies of the entrainment question. Irrevocable decisions to operate or not operate the plant on a once through cooling basis because of the possible impact of the plant on the Hudson River fishery should not be made at this stage. The population model suggests clearly that much additional hard information is necessary before long term impact of the plant on the fishery is known.

It has been clearly demonstrated, however, that no significant damage is to be expected during the next year of operation. Minor perturbations may occur but the system will recover to virtually the same population level that existed before operations began.

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