REVISED 4/30/81

LABORATORY REFERENCE DOCUMENT NO. 81-04

ENTRAINMENT IMPACT OF VIENNA UNIT NO. 9 ON THE STRIPED BASS POPULATION IN THE NANTICOKE RIVER, MARYLAND

by

John Boreman

☑ Approved for Distribution

☐ Distribution to F/NWC, F/SWC, F/SEC, F/NWR1, & F/NEC (Technical Writer-Editor)

Signature

Date 4/30/87

National Marine Fisheries Service
Northeast Fisheries Center
Woods Hole Laboratory
Woods Hole, Massachusetts 02543

INTRODUCTION

Delmarva Power and Light (DPL) is currently proposing to build a new coal-fired power plant unit adjacent to their existing facility in Vienna, Maryland (Portner 1979). The unit will withdraw cooling water from the Nanticoke River in an area of known spawning and nursery habitat for striped bass. In fact, striped bass spawning in the vicinity of Vienna is more concentrated than for any other fish species in the river (Portner and Kohlenstein 1980). Since the Nanticoke River is a major contributor to the total striped bass production in upper Chesapeake Bay (Kohlenstein 1980), the reduction in year class strength due to entrainment mortality at the Vienna site could have an influence on the ability of the Chesapeake stocks of striped bass to recover from their recent decline.

The purpose of this paper is to estimate the level of entrainment mortality imposed by the operation of Vienna Unit No. 9 on the striped bass population in the Nanticoke River. I also examine the relative change in entrainment mortality caused by moving the power plant intake to several alternative sites, and determine which time period would be best for reducing entrainment mortality by means of a continuous four-week plant outage. I rely on biological and physical data collected during the 1978 sampling season, since this data base provides the best information available for estimating the various parameters in the entrainment analysis.

METHOD

My analysis of entrainment impact uses a methodology originally developed for estimating entrainment mortality in six fish populations inhabiting the Hudson River estuary (Boreman et al. 1979), and subsequently used to estimate entrainment impact on the striped bass population in the Potomac River caused by the proposed Douglas Point plant (Boreman et al. 1981). This methodology is termed an Empirical Transport Model (ETM).

The ETM uses life-stage-specific input data for distribution (temporal and spatial), and allows power plant flow rates to vary over time. The equation representing the model formulation used in this paper is:

$$m_T = 1 - \sum_{s=1}^{S} R_s \prod_{j=0}^{J} \prod_{\ell=1}^{L} \sum_{k=1}^{K} D_{\ell k} e^{-E_{s+j,\ell k} C_{j\ell} t_j},$$

where m_T = the conditional entrainment mortality rate,

R_s = the proportion of total eggs spawned during week s in the spawning period, so that

$$\sum_{s=1}^{S} R_s = 1,$$

$D_{s+j,\ell k}$ = the proportion of life stage ℓ organisms in region k during week s+j,

t_j = the duration of age j (always seven days),

C_j = the fraction of age j organisms in life stage ℓ, and

$E_{s+j,\ell k}$ = the instantaneous entrainment mortality rate of life stage ℓ organisms in region k during week s+j (per unit time), which is defined as

$$E_{s+j,\ell k} = \frac{P_{s+j,k} \; f_{s+j,\ell k} \; W_{s+j,\ell k}}{V_k}$$

where $P_{s+j,k}$ = the rate of power plant water withdrawal from region k during week s+j (volume per unit time),

$f_{s+j,\ell k}$ = the fraction of life stage ℓ individuals entering the power plant intake in region k during week s+j that is eventually killed by plant passage,

$W_{s+j,\ell k}$ = the ratio of the average intake to average regional concentration of life stage ℓ individuals in region k during week s+j, and

V_k = the water volume of region k.

A derivation of the equation can be found in Boreman et al. (1978, 1981). The equation yields an estimate of the conditional entrainment mortality rate (CMR), which is defined as the fraction of the initial population which would be killed by entrainment during a specified time period if no other causes of mortality operated. The use of a CMR eliminates the need for estimating natural mortality rates (see Boreman et al. 1978 for a discussion of this property) and can be directly related to the reduction in year class strength, since the CMR is the relative reduction in recruitment to the first non-vulnerable life stage.

INPUT DATA

Parameters of the ETM requiring input data are the fraction of the total spawn that occurs each week (recruitment, R in the equation); the fraction of each life stage present in each region of the estuary (distribution, D); the ratio of the intake concentration to the average cross-sectional concentration of organisms (W-ratio, W) for each life stage; the fraction of organisms entering the intake that are eventually killed (f-factor, f) for each life stage; the duration of each entrainable life stage; the rate of power plant water withdrawal (P); and the volume of the portion of water body subject to withdrawal (V). I relied on the 1978 data base for all the ETM runs. This data was easiest to handle in my analyses, and 1978 was not an odd year for striped bass production in the Nanticoke (unlike 1970 or 1977, Boone 1980).

Recruitment

Table 1 on page II-5 of Portner and Kohlenstein (1980) provides striped bass egg densities (average surface plus bottom) for the 1978 sampling effort by the Chesapeake Bay Institute (CBI). I converted the densities to standing crops by multiplying the densities by the respective region volume for each station (Table 8, page 19, Ibid.). I then summed the standing crops across stations for each day and averaged the totals for all days in a given week. The resultant average weekly total standing crops were then normalized to unity. The fraction of eggs recruited each week in 1978 is presented in Table 1.

Distribution

The average sample densities of eggs and larvae collected in the 1978 sampling season (Tables 1 and 2, Appendix II, Portner and Kohlenstein 1980) were converted to standing crops by multiplying by the respective volume representing the region surrounding each station. Standing crops were then summed across all days for each station for each life stage, and the totals were normalized to unity for each life stage. The region volumes and proportional distributions are listed in Table 2.

I am assuming that all larvae (3-60 days of age) have the same distribution due to a lack of more definitive data. This is unrealistic since distributions tend to reflect the younger, more numerous individuals in a given life stage. The older larvae (30-60 days) are probably distributed further downstream than the above distribution pattern shows. After 60 days, striped bass are no longer vulnerable to entrainment (page 10, ibid.).

W-Ratio:

An analysis of the data presented on pages II-11 through II-54 of Portner and Kohlenstein (1980) showed that, in the Vienna vicinity, eggs were relatively uniform in their vertical distribution (an approximately equal average density in the surface and bottom tows). Larvae, on the other hand, were more concentrated near the bottom (ratios of surface to bottom densities averaged 1:2). Since the W-ratio is the average intake density divided by the average cross-section density, a W-ratio of 1.0 was chosen for eggs and W-ratios of 0.67 and 1.33 were chosen for larvae. A range of W-ratios was used for larvae due to the uncertainty of the intake

location with respect to the larval concentration. If the intake will withdraw from only the upper half of the water column then 0.67 is appropriate; whereas, withdrawal from only the lower half will yield a W-ratio of 1.33. A mid-range of 1.0 was also used in some analyses for easier interpretation of the results. The W-ratios are held constant for all weeks of the entrainment period.

The W-ratios in this analysis do not account for recirculation of discharge water, which could reduce the W-ratio by as much as 10%.

f-Factor

Model runs were made assuming no screens (all f's = 1.0), and assuming the reduction in entrainment mortality due to screens is represented by the function presented in Figure 4 (page 6) of Portner and Kohlenstein (1980): 100% effective for eggs (days 1-3), 0% effective for larvae 4-18 days of age; linearly increasing to 100% effective by age 30 days; and continuing at that level until age 60 days (end of entrainment period). To represent this by f-factors, I arbitrarily divided the 60-day period into four life stages

Life Stage	Duration	f-Factor
1 (egg)	3 days	0
2 (yolksac larvae)	15 days	1.0
3	12 days	0.5
4	30 days	0

Remember that the f-factor is the fraction of organisms entering the intake (in this case susceptible to the intake) that is killed by entrainment. As with the W-ratios, f-factors are held constant for all weeks of the entrainment period.

Plant Withdrawal Rate

The power plant withdrawal flow used in the model was 43.06 x $10^3 m^3$ per day (Table 7, ibid.). The rate is assumed to remain constant throughout the entrainment period, except in cases reflecting shut-downs when the rate for a given week was set equal to zero.

Volumes

The volumes of the seven regions used in the model are presented in Table 2. Since the average tidal excursion is approximately 6.5 nautical miles (Table 3, Page 9, ibid.), water susceptible to withdrawal may originate in Region 6, 8 (Vienna), or 10. I, therefore, arbitrarily assumed that 30% of the plant's daily water withdrawal originates from region 6, 40% from region 8, and 30% from region 10 to reflect tidal movements in front of the intake.

RESULTS AND DISCUSSION

Results of ETM runs with W-ratios for larvae equal to 0.67, 1.0, and 1.33, and the intake located at Station 6, Station 8 (Vienna), and Station 10 are presented in Table 3. The computer program used for the runs is listed in Appendix I. The results for Vienna are similar to the results presented by Portner and Kohlenstein (1980) (2.3% with screens and 5.0% without screens, pages 20-21). The results at Vienna that I obtained are much higher than those obtained by the utility (0.8%, page A(II) 2.7b-8 in DPL 1979), who used a one-dimensional hydrodynamic transport model. However the utility used a different screen survival function which shortened

the period of vulnerability.

Moving the intake to Station 6, which is approximately six nautical miles downriver, will result in an increase in impact of about 1.2X. This is due to the greater concentration of the more vulnerable life stage (yolksac larvae) at the lower station (Table 2). Moving the intake to station 10 (4 miles upriver) will reduce entrainment impact about 70-75%. The upriver station had a much lower relative abundance of both eggs and larvae (Table 2).

Shut-Down Schedule

Results of the ETM runs assuming a four-week shut-down during the entrainment season and W = 1.0 for larvae are presented in Table 4. From this analysis, a four-week shut-down from mid-April to mid-May would reduce the entrainment mortality by approximately 80%. A four-week shut-down any time during April or May will reduce entrainment mortality by approximately 45-80%.

One must keep in mind that these analyses are based on the 1978 data base and, therefore, reflect what might happen if the future conditions in the Nanticoke River are similar to the conditions that existed in 1978. A more definitive analysis would include an average of several years of data (the more the better). Furthermore, the spatial and temporal occurrence of eggs, yolksac larvae, post yolksac larvae, and entrainable juveniles in the Nanticoke population of striped bass needs better definition. As mentioned earlier, the distributions and depth characteristics used in this analysis are probably not truly reflective of the older individuals (age

30-60 days). The mortality estimate is also extremely sensitive to the function used to characterize the reduction in entrainment mortality caused by the presence of the fine mesh screens. This function, therefore, needs to have a high level of precision and accuracy.

LITERATURE CITED

Boone, J.G. 1980. Estuarine fish recruitment survey, July 1, 1979 through June 30, 1980. Performance Report, State of Maryland, Project F-27-R-6.

Boreman, J., C.P. Goodyear, and S.W. Christensen. 1978. An empirical transport model for evaluating entrainment of aquatic organisms by power plants. U.S. Fish and Wildlife Service. FWS/OBS-78/90. 67 pp.

Boreman, J., L.W. Barnthouse, D.S. Vaughan, C.P. Goodyear, and S.W. Christensen. 1979. Entrainment impact estimates for six fish populations inhabiting the Hudson River estuary. Prepared for the U.S. Environmental Protection Agency, Region II.

Boreman, J., C.P. Goodyear, and S.W. Christensen. 1981. An empirical methodology for estimating entrainment losses at power plants sited on estuaries. Transactions of the American Fisheries Society. 110(2) (in press).

(DPL) Delmarva Power and Light. 1979. Application for certificate of public convenience and necessity for Vienna Power Station Unit 9.

Kohlensten, L.C. 1980. Aspects of the population dynamics of striped bass (Morone saxatilis) spawning in Maryland tributaries of the Chesapeake Bay. Johns Hopkins University. JHU PPSE T-14.

Portner, E.M. 1980. Impacts of the proposed Vienna Unit No. 9 - An Overview of Vienna and alternative sites. Johns Hopkins University. JHU PPSE 8-8.

Portner, E.M., and L.C. Kohlenstein. 1979. Prediction of entrainment/impingement impact for striped bass eggs and larvae by the proposed Vienna Unit No. 9. Johns Hopkins University. JHU PPSE 8-1.

Table 1. Fraction of striped bass eggs sampled each week, the Nanticoke River, Maryland, during 1978.

Week	Average Standing Crop[1] ($\times 10^{-7}$)	Fraction
4/3 - 4/9	3.69	0.02
4/10 - 4/16	44.40	0.26
4/17 - 4/23	62.50	0.37
4/24 - 4/30	31.37	0.18
5/1 - 5/7	25.95	0.15
5/8 - 5/14	2.80	0.02
5/15 - 5/21	0.23	0.00
5/22 - 5/28	0.17	0.00

[1]Based on Table 1, Appendix II in Portner and Kohlenstein (1980).

Table 2. Proportional distributions, expressed as percentages, of striped bass eggs and larvae in the Nanticoke River, Maryland, during 1978.

CBI Station	Volume[1] (1000 m^3)	Eggs (%)	Larvae (%)
2	26000	0	0
4	22800	4	12
6	16800	42	72
8	11600	52	14
10	7000	1	1
11	6000	1	1
12	7600	0	0

[1]From Table 8 in Portner and Kohlenstein (1980).

Table 3. Estimated conditional entrainment mortality rates of striped bass, expressed as percentages, for various intake locations of the proposed Vienna Unit No. 9 on the Nanticoke River, Maryland.

Intake Location	Type of Intake	W-Ratio for Larvae		
		0.67	1.0	1.33
CBI Station 6 (Athaloo Lodge)	No screens	3.9	5.6	7.3
	Screens	1.3	2.0	2.7
CBI Station 8 (Vienna)	No screens	3.3	4.7	6.1
	Screens	1.1	1.6	2.2
CBI Station 10 (Maryshope Creek)	No screens	1.0	1.3	1.7
	Screens	0.3	0.4	0.6

Table 4. Estimated conditional entrainment mortality rates of striped bass expressed as percentages, based on a continuous four-week shut-down of the proposed Vienna Unit No. 9 and the 1978 data base.

Shut-Down Dates	Mortality
4/3 - 4/30	0.9
4/10 - 5/7	0.5
4/17 - 5/14	0.3
4/24 - 5/21	0.4
5/1 - 5/28	0.8
5/8 - 6/4	1.1
5/15 - 6/11	1.4
5/22 - 6/18	1.5
5/29 - 6/25	1.6
6/5 - 7/2	1.6
6/12 - 7/9	1.6
6/19 - 7/16	1.6

APPENDIX I. Computer Program, written in BASIC language, used to estimate the conditional entrainment mortality rate of striped bass at Vienna Unit No. 9, Nanticoke River, Maryland.

```
100      RESTORE
101 REM I9=NUMBER OF WEEKS IN THE ENTRAINMENT PERIOD
102 REM J9=TOTAL NUMBER OF AGES
103 REM K9=TOTAL NUMBER OF REGIONS
104 REM P9=TOTAL NUMBER OF PLANTS
105 REM L9=TOTAL NUMBER OF LIFE STAGES
106 REM T=NUMBER OF DAYS IN TIME STEP
107 REM F9=F-FACTOR FOR EACH LIFE STAGE
108 REM W9=W-RATIO FOR EACH LIFE STAGE
109 REM D=DISTRIBUTION BY LIFE STAGE
110 REM P8=POWER PLANT WITHDRAWAL RATE BY WEEK
111 REM X=LIFE STAGE TO AGE CONVERSION MATRIX
112 REM R=EGG RECRUITMENT PROPORTIONS
113 REM V=REGION VOLUMES (TCM)
114 REM E=INSTANTANEOUS ENTRAINMENT MORTALITY RATE
115 REM W9=PROPORTION OF PP FLOW WITHDRAWN FROM EACH REGION
116 REM F=F-FACTOR TIMES W-RATIO
117 REM O=TOTAL NUMBER OF EGGS SPAWNED
200      I9=15
300      J9=10
400      K9=7
500      P9=1
600      L9=5
700      T=7
800      O=1E+8
801 REM INITIALIZE
900      DIM F(1,5),P8(15,1),D(7,5),X(10,5),F9(1,5)
1000     DIM R(15),V(7),W(1,7),C(10),E(7,5),W9(1,5)
1001     MAT F = ZER
1002     MAT P8 = ZER
1003     MAT D = ZER
1004     MAT X = ZER
1005     MAT F9 = ZER
1006     MAT R = ZER
1007     MAT V = ZER
1008     MAT W = ZER
1009     MAT W9 = ZER
1101 REM READ IN F-FACTORS
1200     FOR P=1 TO P9
1300     FOR L=1 TO L9
1400     READ F9(P,L)
1500     NEXT L
1600     NEXT P
1700     DATA 0,1,0.5,0,0
```

APPENDIX I (cont.)

```
1701 REM READ IN W-RATIOS
1800    FOR P=1 TO P9
1900    FOR L=1 TO L9
2000    READ W9(P,L)
2100    F(P,L)=W9(P,L)*F9(P,L)
2200    NEXT L
2300    NEXT P
2400    DATA 1,1,1,1,1
2401 REM READ IN PLANT FLOW RATES
2500    FOR I=1 TO I9
2600    FOR P=1 TO P9
2700    READ P8(I,P)
2800    NEXT P
2900    NEXT I
3000    DATA 43.06,43.06,43.06,43.06,43.06,43.06,43.06,43.06
3100    DATA 43.06,43.06,43.06,43.06,43.06,43.06,43.06
3102 REM READ IN LIFE STAGE DISTRIBUTIONS
3200    FOR K=1 TO K9
3300    FOR L=1 TO L9
3400    READ D(K,L)
3500    NEXT L
3600    NEXT K
3700    DATA 0,0,0,0,1
3800    DATA 0.04,0.12,0.12,0.12,0
3900    DATA 0.42,0.72,0.72,0.72,0
4000    DATA 0.52,0.14,0.14,0.14,0
4100    DATA 0.01,0.01,0.01,0.01,0
4200    DATA 0.01,0.01,0.01,0.01,0
4300    DATA 0,0,0,0,0
4301 REM READ IN LIFE STAGE TO AGE CONVERSION MATRIX
4400    FOR J=1 TO J9
4500    FOR L=1 TO L9
4600    READ X(J,L)
4700    NEXT L
4800    NEXT J
4900    DATA 0.4286,0.5714,0,0,0
5000    DATA 0,1,0,0,0
5100    DATA 0,0.5714,0.4286,0,0
5200    DATA 0,0,1,0,0
5300    DATA 0,0,0.2857,0.7143,0
5400    DATA 0,0,0,1,0
5500    DATA 0,0,0,1,0
5600    DATA 0,0,0,1,0
5700    DATA 0,0,0,0.5714,0.4286
5800    DATA 0,0,0,0,1
```

APPENDIX I (cont.)

```
5801 REM READ IN EGG RECRUITMENT PROPORTIONS
5900    FOR I=1 TO I9
6000    READ R(I)
6100    NEXT I
6200    DATA 0.02,0.26,0.37,0.18,0.15,0.02,0,0,0,0,0,0,0,0,0
6201 REM READ IN REGION VOLUMES
6300    FOR K=1 TO K9
6400    READ V(K)
6500    NEXT K
6600    DATA 26000,22800,16800,11600,7000,6000,7600
6601 REM READ IN PROPORTIONAL WITHDRAWAL FRACTIONS
6700    FOR P=1 TO P9
6800    FOR K=1 TO K9
6900    READ W(P,K)
7000    NEXT K
7100    NEXT P
7200    DATA 0,0,0.3,0.4,0.3,0,0
7300    MAT C = ZER
7301 REM BEGIN TIME STEPS
7400    FOR I=1 TO I9
7500    C(1) = O*R(I)
7600    GOSUB 9400
7650 REM CALCULATE THE REDUCTION DUE TO ENTRAINMENT
7700    FOR J=1 TO J9-1
7750    FOR L=1 TO L9
7800    S=0
7900    FOR K=1 TO K9
8100    S=S+C(J)*D(K,L)*(1-EXP(-(E(K,L)*T*X(J,L))))
8200    NEXT K
8400    C(J)=C(J)-S
8450    NEXT L
8500    NEXT J
8600    C(J9)=C(J9)+C(J9-1)
8601 REM ADVANCE AGE VECTOR
8700    FOR J=J9-1 TO 2 STEP -1
8800    C(J)=C(J-1)
8900    NEXT J
9000    NEXT I
9100    M=1-C(J9)/O
9200    PRINT "TOTAL ENTRAINMENT MORTALITY IS "$M
9300    GO TO 10500
```

APPENDIX I (cont.)

```
9301 REM CALCULATE INSTANTANEOUS ENTRAINMENT MORTALITY RATE
9400     MAT E = ZER
9500     FOR P=1 TO P9
9600     W1=PB(I,P)
9700     FOR L=1 TO L9
9800     F1=F(P,L)
9900     FOR K=1 TO K9
10000    E(K,L)=E(K,L)+F1*W1*W(P,K)/V(K)
10100    NEXT K
10200    NEXT L
10300    NEXT P
10400    RETURN
10500    END
```