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THE IMPACT OF IMPINGEMENT ON THE HUDSON RIVER WHITE PERCH POPULATION

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L. W. Barnthouse and W. Van Winkle
Environmental Sciences Division
Oak Ridge National Laboratory*
Oak Ridge, Tennessee 37830

The impact of power plant impingement on the 1974 and 1975 year classes of the Hudson River white perch population is assessed using a simple model derived from Ricker's theory of fisheries dynamics. The only data required are estimates of the initial number of impingeable juveniles, the number impinged, and the rate of total mortality during the period of vulnerability. The impact of impingement is expressed in the model as the conditional mortality rate, rather than as the more commonly used exploitation rate. The conditional mortality rate is superior as a measure of impact for two reasons: it accounts for the differential impact of impinging fish of different ages, and it is numerically equivalent to the fractional reduction in year-class abundance due to impingement.

Since the calculated impact is sensitive to errors in the estimation of population size and total mortality, ranges of probable values of these quantities are used to compute upper and lower bounds on the fractional reduction in abundance of each year class. Best estimates of abundance and mortality are used to compute the conditional impingement mortality rate separately for each plant and month. The results are used to assess the relative impacts of white perch impingement at six Hudson River power plants and to identify the seasons during which the impact is highest.

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INTRODUCTION

Large numbers of white perch, ranging in age from young-of-the-year through adult, are impinged each year on the intake screens of six power plants on the Hudson River: Bowline, Lovett, Indian Point, Roseton, Danskammer, and Albany. Concern about the magnitude of this impingement and its potential effects on the Hudson River white perch population were expressed in the U.S. Nuclear Regulatory Commission's (USNRC) Final Environmental Statement for Indian Point Unit 3 (USNRC 1975). In response to this concern, USNRC's Office of Nuclear Regulatory Research has funded research at Oak Ridge National Laboratory with the goal of evaluating the biological significance of impingement losses of white perch at Indian Point and other Hudson River power plants. The objectives of the portion of our work described in this paper were (1) to estimate the impacts of impingement on the 1974 and 1975 white perch year classes, (2) to identify the plants responsible for the greatest impact, and (3) to identify the seasons during which the greatest impact occurs. Our results can aid in determining whether mitigating measures should be implemented to protect this population, at which plants mitigation would be most effective, and during which seasons mitigation is most important.

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METHODS

Analytical Methodology

This analysis was performed using a simple model (Barnthouse, DeAngelis, and Christensen 1979) derived from Ricker's theory of fisheries dynamics. The measure of impact computed using this model is the conditional mortality rate (Ricker 1975, p. 9). As applied to impingement, the conditional mortality rate is defined as the fraction of the vulnerable population that would be killed by impingement in the absence of mortality from all other sources, both natural and anthropogenic (throughout this paper we denote mortality from all other sources as "natural" mortality). The conditional impingement mortality rate has three major advantages over other quantitative estimates of impact. First, it is numerically equal to the fractional reduction in year-class abundance due to impingement, provided that density-dependent mortality is negligible during the period of vulnerability to impingement. Second, it accounts for the differential impact of impinging fish of different ages and, when properly calculated, it accounts for the effects of seasonal variations in impingement. Third, the only data required are estimates of the abundance of each year class at the time juveniles become vulnerable to impingement, monthly counts of the number of fish impinged, and monthly estimates of the rate of total mortality during the period of vulnerability.

We have not attempted to extrapolate estimates of the direct impact of impingement on single year classes to estimates of the long-term impact on the white perch population as a whole. Such extrapolations would have little value because the effects of compensatory processes, which undoubtedly operate in this population, cannot be validly quantified from any existing data.

Given the data described above, the conditional impingement mortality rate, computed for an arbitrarily defined time interval, is given by:

$$m = 1-(1-A)^{u/A} , \tag{1}$$

where

- m = conditional impingement mortality rate,
- u = impingement exploitation rate (number of fish impinged / initial population size), and
- A = fraction of the initial population dying from all causes during the time interval.

If the time interval chosen is the entire period of vulnerability of a year class, and if the exploitation rate estimate includes all members of that year class that were impinged, then the value computed using equation 1 is an estimate of the total conditional impingement mortality rate (m_I) for that year class. We found it desirable, however, (1) to break down A into components due to impingement mortality and natural mortality, (2) to set the time interval for calculation equal to one month rather than to the entire period of vulnerability, and (3) to calculate separate conditional impingement mortality rates for each of six power plants.

The two components of A are the conditional impingement mortality rate (m) and the conditional natural mortality rate (n), which is defined as the fraction of the initial population that would die of natural causes if there were no impingement. Expressing A in terms of m and n enabled us to compute conditional impingement mortality rates for two different year classes using a single estimate of natural mortality. Equation 1 can be formulated in terms of natural mortality simply by substituting $(1-(1-m)(1-n) = m+n-mn)$ for A. A complete derivation of equation 1, including a method of calculating n, given that A and u are known, is presented elsewhere (Barnthouse, DeAngelis, and Christensen 1979).

For this assessment we employed a time interval of one month in order to account for seasonal fluctuations in impingement. Such fluctuations can introduce substantial errors into estimates of m computed using annual or longer time intervals (Barnthouse, DeAngelis, and Christensen 1979). We computed separate monthly values of m for each power plant. Assuming independence among months and among power plants, these values combine like independent probabilities to yield estimates of the total conditional impingement mortality rate for each plant ($m_{i.}$) and for all six plants combined (m_I):

$$m_{i.} = 1 - \prod_{j=1}^{k} (1-m_{ij}) , \qquad (2)$$

$$m_I = 1 - \prod_{i=1}^{6} (1-m_{i.}) , \qquad (3)$$

where

k = number of months during which fish are vulnerable to impingement, and

m_{ij} = conditional impingement mortality rate for plant i during month j.

Initial population sizes for all months, following the first month, are computed in sequence:

$$N_j = N_{j-1}(1-m_{.j}) (1-n_j) , \qquad (4)$$

where

N_j = population size at end of month j

$m_{.j}$ = conditional impingement mortality rate during month j, all plants combined, and

n_j = conditional natural mortality rate during month j.

Abundance, mortality, and impingement estimates

Estimates of the abundance of young-of-the-year white perch in October 1974 and October 1975 were obtained from a mark/recapture program conducted by Texas Instruments, Inc. (McFadden and Lawler 1977). These estimates (Table 1) are based on winter and spring recaptures of finclipped white perch released the previous fall. Descriptions of the methods used in data collection and analysis can be found in reports prepared by Texas Instruments for the Consolidated Edison Co. of New York (Texas Instruments 1975a, 1978). Like any population estimates, Texas Instruments' mark/recapture estimates are subject to sampling error and to a variety of potential biases. For this reason we performed alternative calculations of m_I using ranges of abundance estimates for each year class (Table 1). The upper and lower bounds chosen were the upper and lower 95% confidence limits presented by McFadden and Lawler (1977). Since young-of-the-year white perch begin to appear in impingement collections in mid-July, we chose July 16 as the starting date for the period of vulnerability to impingement. The October mark/recapture estimates were extrapolated backwards July 16 using the daily instantaneous mortality rates discussed below.

Data presented by Dew (1978) and by Wallace (1971) indicate that total mortality among yearling and older white perch is about 50% per year. Van Winkle et al. (1980) applied Robson and Chapman's (1961) catch-curve method to Dew's data on yearling and older white perch in the Hudson and obtained a value of 0.49. Wallace estimated mortality among age 1-4 white perch in the Delaware River to be 0.54 for males and 0.58 for females. We believe that 0.50 is a reasonable estimate of annual mortality (A), and this is the value we used in our assessment.

None of the available data appear adequate for deriving reliable estimates of total mortality in young-of-the-year white perch. We have, therefore, used a range of values. As a high estimate we used the value of 0.80 assumed by McFadden and Lawler (1977). For reasons discussed by Van Winkle et al. (1980), this value is probably an overestimate. Alternatively, we have assumed that mortality among impingeable young-of-the-year is identical to that among yearling and older fish, i.e., about 0.5. Since young-of-the-year probably suffer higher mortality than older fish, this value is probably an underestimate.

We have formulated the model in terms of natural mortality (n) even though only total mortality (A) is directly measureable. A and n are, for practical purposes, indistinguishable when natural mortality is high relative to impingement mortality. For example, the value of n calculated by Barnthouse, DeAngelis, and Christensen (1979) for young-of-the-year striped bass was 0.79, only trivially smaller than the total mortality rate of 0.80. We have assumed throughout this analysis that n is approximately equal to A. We calculated monthly values of n from the annual values using the following procedure. The annual instantaneous natural mortality rate (M) is equal to $-\ln(1-n)$. Given M, the daily instantaneous natural mortality rate (r_n) is equal to M/365 (Table 1, footnote b). Monthly conditional natural mortality rates (n_j) are equal to $1-\exp(-d_j r_n)$, where d_j is the number of days in month j.

Estimates of the number of white perch impinged and killed by Hudson River power plants during 1974-77 were calculated by Van Winkle et al. (1980) from data obtained from the Hudson River utilities. It was assumed that, for all plants except Indian Point (where all impinged fish are collected), factors promoting overestimates (principally the survival of impinged fish) and underestimates (principally collection efficiency) of impingement are roughly equal in magnitude. It appears from data on the length-frequency distribution of impinged white perch that relatively few fish older than age II are impinged. Young-of-the-year white perch are readily distinguished from older fish on the basis of size, but yearlings cannot be clearly distinguished from two-year-olds. Therefore, we employed two alternative assumptions about the age distribution of the impingement "catch." First, we assumed that all impinged white perch older than age 0 are yearlings, resulting in two years of vulnerability to impingement. Alternatively, we assumed that half of these fish are yearlings and half are two-year-olds, resulting in three years of vulnerability to impingement. It is likely that the true split between yearlings and two-year-olds lies between these extremes. The impingement estimates used in our analysis are presented in Table 2.

RESULTS

We applied the empirical model described above using all combinations of estimates of initial abundance, mortality, and period of vulnerability of the 1974 and 1975 white perch year classes. Because no age-frequency distributions were available for impingement collections beyond December 1977, we could could not compute m_I for the 1975 year class under the assumption of three years of vulnerability to impingement. Table 3 contains the ranges of estimates of m_I, for both year classes, for all plants combined. These estimates indicate that under the most optimistic assumptions, i.e., high abundance, low natural mortality, and two years of vulnerability, impingement at Hudson River power plants reduced the size of the 1974 white perch year class by about 10% and of the 1975 year class by about 8%. Under the most pessimistic assumptions, the size of the 1974 year class was reduced by 59%. Overall, the estimates of m_I indicate a probable 20% or larger reduction in the size of the 1974 year class because of impingement. Given that we could compute m_I for the 1975 year class only under the optimistic assumption of two years of vulnerability, our results indicate a probable 15% or larger reduction in the abundance of this year class.

The reproductive value of a sexually immature fish increases with its age, because its probability of surviving to maturity increases. For this reason, the impact to a population of killing an immature fish increases with its age (Barnthouse, DeAngelis, and Christensen 1979). Thus, the impingement of yearling and two-year-old white perch has a substantially greater impact on the white perch population than is indicated by their contribution to the impingement counts. In Table 4 we have tabulated the contributions of yearling and older white perch to m_I, under assumptions yielding low (low young-of-the-year natural mortality and two years of vulnerability) and high (high young-of-the-year natural mortality and three years of vulnerability) contributions for these fish. Assuming two years of vulnerability and low young-of-the-year mortality, yearling and older white perch accounted for only 8% of the total impingement count for the 1974 year class. Yet the contribution of these fish to m_I is about 20% (0.028/0.153) as high as the contribution of young-of-the-year. Under the assumption of three years of vulnerability, the contribution of yearling and older fish is about 75% as high as the contribution of young-of-the-year. The contribution of yearling and older fish to m_I for the 1975 year class is even higher than for 1974.

Table 5 contains an analysis of the contribution of each of six power stations to m_I for each year class. Since these results are relatively insensitive to assumptions about abundance, mortality, and length of the period of vulnerability, we present the analysis for a single reference case: best estimate of initial population size, high natural mortality, and two years of vulnerability. These results show that the impact of the Indian Point Nuclear Station (Units 1, 2, and 3 combined) was, for both year classes, greater than the combined impact of the other five plants. Interestingly, the contributions of Bowline and Lovett were smaller in comparison to those of Roseton, Danskammer, and Albany than would be expected based on their contributions to the impingement counts. The explanation for this result is that relatively more yearling and older white perch are impinged at the latter three plants (Van Winkle et al. 1980).

Figure 1 shows an analysis of the above reference case by season. For both year classes, substantial impacts occurred only during winter (December-February) and spring (March-May). Not surprisingly, the seasonal pattern of impacts for all plants combined is closely matched by the seasonal pattern at Indian Point. The combined impact of the other five plants is spread relatively evenly over the year.

DISCUSSION

Our analysis shows that the abundance of the 1974 white perch year class in the Hudson River was reduced by at least 10%, and probably by 20% or more, because of impingement. The abundance of the 1975 year class was reduced by at least 8%, and probably by 15% or more. These impact estimates do not include consideration of entrainment, so that the total impact of power plants on these year classes was even greater than is indicated by our analysis.

The fact that yearling and older white perch are vulnerable to impingement contributes to the surprisingly high impact of impingement on this population. However, it is the seasonal distribution of white perch that is primarily responsible for their vulnerability. These fish migrate to the lower and middle estuary, where the Bowline, Lovett, and Indian Point plants are located, during the late fall and remain there through the winter (McFadden 1977). Studies conducted by Texas Instruments (1974, 1975b) suggest that the high levels of winter impingement of white perch at Indian Point may be related to their preference for deep areas of the Hudson River channel. In the vicinity of Indian Point the channel is located along the east shore of the Hudson, adjacent to the Indian Point intakes. Impingement "events" at Indian Point are also related to the presence of high concentrations of white perch in the vicinity of the salt front, which fluctuates above and below the plant during the winter. The mobility of these overwintering fish, and consequently, their ability to avoid intake structures, is probably reduced because of near-freezing water temperatures.

Given the information presently available, it is our judgment that the level of impingement impact on the Hudson River white perch population is high enough to warrant mitigation. Since the Indian Point Generating Station is responsible for most of the impact, mitigating impingement at Indian Point is the most effective way to protect this population. This could be accomplished either by reducing the number of fish impinged or by increasing the survival rate of impinged fish. Since impingement at Indian Point occurs primarily during winter and early spring, any mitigating devices installed must be effective at low temperatures in order for the impact to be substantially reduced.

BIBLIOGRAPHY

Barnthouse, L. W., D. L. DeAngelis, and S. W. Christensen. 1979. An Empirical Model of Impingement Impact. ORNL/NUREG/TM-290. Oak Ridge National Laboratory, Oak Ridge, Tennessee.

Dew, C. B. 1978. Age, growth, and mortality of Hudson River white perch (Morone americana) and the use of these parameters in evaluating the exploitation rate represented by impingement at power plant intakes. Presented at the Northeast Fish and Wildlife Conference, Greenbriar, West Virginia. February 28, 1978.

McFadden, J. T. (ed.). 1977. Influence of Indian Point Unit 2 and Other Steam Electric Generating Plants on the Hudson River Estuary, with Emphasis on Striped Bass and Other Fish Populations. Consolidated Edison Company of New York, Inc.

McFadden, J. T., and J. P. Lawler (eds.). 1977. Supplement I to Influence of Indian Point Unit 2 and Other Steam Electric Generating Plants on the Hudson River Estuary, with Emphasis on Striped Bass and Other Fish Populations. Consolidated Edison Company of New York, Inc.

Ricker, W. E. 1975. Computation and Interpretation of Biological Statistics of Fish Populations. Fish. Res. Board Can., Bull. 191. 382 p.

Robson, D. S., and D. G. Chapman. 1961. Catch curves and mortality rates. Trans. Am. Fish. Soc. 90:181-189.

Texas Instruments, Inc. 1974. Hudson River Ecological Survey in the Area of Indian Point. 1973 Annual Report. Consolidated Edison Company of New York, Inc.

Texas Instruments, Inc. 1975a. First Annual Report for the Multiplant Impact Study of the Hudson River, Vol. I, July, 1975. Consolidated Edison Company of New York, Inc.

Texas Instruments, Inc. 1975b. Indian Point Impingement Study Report for the Period 1 January 1974 through 31 December 1974. Consolidated Edison Company of New York, Inc.

Texas Instruments, Inc. 1978. 1975 Year-Class Report for the Multiplant Impact Study of the Hudson River Estuary. Consolidated Edison Company of New York, Inc.

USNRC (U.S. Nuclear Regulatory Commission). 1975. Final Environmental Statement Related to Operation of Indian Point Nuclear Generating Plant Unit No. 3, Consolidated Edison Company of New York, Inc. NUREG-75/002.

Van Winke, W., L. W. Barnthouse, B. L. Kirk, and D. S. Vaughan. 1980. Evaluation of Impingement Losses of White Perch at the Indian Point Nuclear Station and Other Hudson River Power Plants. ORNL/NUREG/TM-361. Oak Ridge National Laboratory, Oak Ridge, Tennessee. (in press)

Wallace, D. C. 1971. Age, growth, year class strength, and survival rates of the white perch, _Morone americana_ (Gmelin) in the Delaware River in the vicinity of Artificial Island. Chesapeake Science 12:205-218.

Table 1. Initial population sizes and estimates of natural mortality for young-of-the-year white perch in the Hudson River.

Date	Type of estimate[a]	Natural mortality[b]	Population size ($x10^6$) 1974	1975
October 1[c]	LB		12	21
	BE		21	30
	UB		39	45
July 16[d]	LB	Low	13.9	24.3
		High	16.8	29.4
	BE	Low	24.3	34.7
		High	29.4	41.9
	UB	Low	45.1	52.0
		High	54.5	62.9

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

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

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

[c] Size of the Hudson River young-of-the-year white perch population on October 1, as estimated by Texas Instruments using mark-recapture techniques (McFadden and Lawler, 1977, p. 2-VII-2, as modified by errata).

[d] Size of the Hudson River young-of-the-year white perch population on July 16. It is calculated using the equation

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

where values for $P_{October\ 1}$ and r_n are given elsewhere in this table and 76 is the number of days between July 16 and October 1.

Table 8. Monthly estimates of the number of white perch impinged at all the Hudson River power plants combined for the 1974 and 1975 year classes[a]

		Year class			
		1974		1975	
		Number of years of vulnerability		Number of years of vulnerability	
Age (years)	Month	2	3	2	3
0	6	0		0	
	7	3,486		8,898	
	8	14,887		97,910	
	9	26,239		83,980	
	10	112,957		93,888	
	11	245,492		239,150	
	12	607,434		348,596	
	1	415,724		589,206	
	2	270,571		182,891	
	3	139,751		130,261	
	4	609,090		111,820	
	5	91,910		40,151	
1	6	37,242	18,621	27,014	13,507
	7	22,126	11,063	13,835	6,918
	8	14,122	7,061	6,770	3,385
	9	19,924	9,962	13,791	6,896
	10	19,534	9,767	25,676	12,838
	11	28,005	14,002	12,552	6,276
	12	7,803	3,902	48,102	24,051
	1	38,078	19,039	143,010	71,505
	2	9,293	4,646	43,558	21,779
	3	12,444	6,222	49,579	24,790
	4	14,103	7,052	38,692	19,346
	5	7,612	3,806	56,365	28,183
2	6		13,507		35,710
	7		6,918		8,805
	8		3,385		12,662
	9		6,896		8,736
	10		12,838		17,362
	11		6,276		19,145
	12		24,051		10,890
	1		71,505		
	2		21,779		
	3		24,790		
	4		19,346		
	5		28,182		

[a]From Table 7 of Van Winkle et al. (1980).

Table 3. Estimates of total conditional impingement mortality rates (m_I) and impingement exploitation rates (in parentheses) for the 1974 and 1975 year classes of the Hudson River white perch population. Estimates were computed using all combinations of assumptions about initial population size, natural mortality, and number of years of vulnerability.[a]

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

[a]Total conditional impingement mortality rate calculated using Eq. (3) in text. Total conditional impingement mortality rates are equal to fractional (or percent) reductions in year-class strength due to impingement, assuming no compensation.

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

[b]See Table 2.

[c]See Table 1.

[d]See footnote b to Table 1.

Table 4. Contributions of age 0 versus age 1+ white perch to impingement counts and to conditional impingement mortality rates for representative cases yielding low and high contributions of older fish to m_I.[a]

		Age 0		Age 1+	
Year Class	Case	Fraction of impingement count	m_0	Fraction of impingement count	m_{1+}
1974	Low natural mortality, 2 years of vulnerability[b]	0.917	0.153	0.083	0.028
1975	Low natural mortality, 2 years of vulnerability[b]	0.801	0.077	0.199	0.043
1974	High natural mortality, 3 years of vulnerability[c]	0.878	0.211	0.122	0.158

[a] All cases use the best estimates of population size (Table 1).

[b] Assumptions yielding low contributions of age 1+ impingement to the conditional impingement mortality rate are low age 0 mortality and 2 years of vulnerability to impingement.

[c] Assumptions yielding high contributions of age 1+ impingement to conditional impingement mortality rate are high age 0 mortality and 3 years of vulnerability to impingement.

Table 5. Relative contributions of six power plants to impingement counts and plant-specific conditional impingement mortality rates ($m_{i.}$) for the 1974 and 1975 white perch year classes.[a]

	1974 Year Class		1975 Year Class	
Plant[b]	Fraction of impingement count	$m_{i.}$	Fraction of impingement count	$m_{i.}$
Bowline	0.134	0.033	0.066	0.013
Lovett	0.034	0.008	0.020	0.003
Indian Point	0.771	0.197	0.764	0.124
Roseton	0.023	0.011	0.067	0.016
Danskammer	0.025	0.011	0.058	0.016
Albany	0.017	0.011	0.025	0.008

[a]Analysis for reference case (best estimate of initial population, high age 0 natural mortality, 2 years of vulnerability).

[b]All units combined.

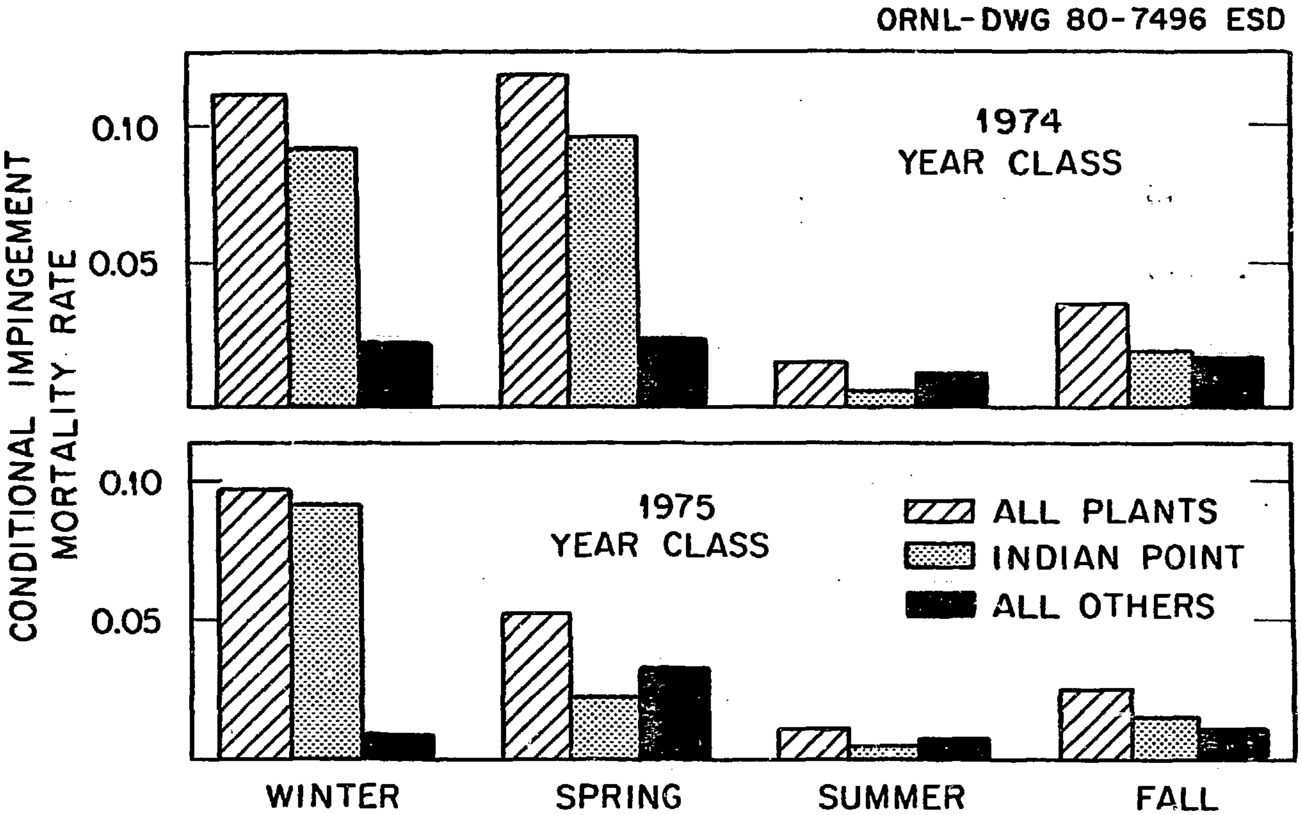

Figure 1. Seasonal comparison of conditional impingement mortality rates for all plants combined, for Indian Point (all units combined) and for all other plants combined.