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ESTIMATES OF THE EQUIVALENT LOSS OF ENTRAINMENT AND IMPINGEMENT AT THE MERRIMACK GENERATING STATION

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BACKGROUND AND ANNUAL ENTRAINMENT AND IMPINGEMENT ESTIMATES AND TARGET SPECIES SELECTION

This report provides estimates of the adult equivalents lost due to entrainment and impingement at the Merrimack Generating Station for use in a benefit-cost study of fish protection alternatives being performed by NERA Economic Consulting. This chapter provides a description of the facility and an overview of the methods used to estimate annual entrainment and impingement. In addition, this chapter briefly discusses the species of fish that were selected for analysis.

MERRIMACK GENERATING STATION

The Merrimack Generating Station (Merrimack) is a generating station consisting of two generating units, Unit 1 and Unit 2. Unit 1 has a net capacity of 120 MW and Unit 2, 350 MW. The facility design cooling water flow is 285.6 MGD. Mean total cooling water flow summed over both units during 316(b) studies from June 2005 to June 2007 was 216 million gallons per day. Merrimack is located on the Hooksett Pool within the freshwater portions of the Merrimack River from which it draws cooling water. This facility has a shoreline intake with standard 3/8-inch traveling screens.

ANNUAL ENTRAINMENT AND IMPINGEMENT ESTIMATES

Estimates of the annual entrainment and impingement that formed the basis for this assessment were developed from an impingement and entrainment monitoring program conducted at the facility during 2005-2007 (NAI 2007). A brief summary of the methods and results of this monitoring program are provided below.

Entrainment Monitoring

Entrainment monitoring was conducted in 2006 and 2007 (NAI 2007). During 2006, entrainment sampling was conducted at both Units 1 and 2 from late-May through mid-September. The scheduled sampling was weekly from late May through August (15 sampling weeks) and bi-weekly during the first half of September (one sampling week). Sampling was restarted during early April of 2007 and continued through June 2007. The scheduled sampling was biweekly from early April to mid May (four sampling weeks) and weekly during the remainder of the 2007 period (nine sampling weeks). Entrainment sampling was not conducted at an individual unit on days when one or both of the two circulating pumps were not operating. On each sampling day, one daytime sample and one nighttime sample were collected.

Entrainment survival studies were attempted, however no fish eggs or larvae were collected (egg and larval densities were apparently too low) and this attempt was not pursued.

Entrainment samples were collected through a 0.300-mm mesh plankton net suspended over a barrel sampler located outside of the pump houses at Units 1 and 2. Water was supplied to each sampler from a 3-inch raw-water tap drawing unchlorinated ambient cooling water from the condenser supply line. Flow was calculated for each sample using a timed volumetric method to ensure that a sample volume of at least 100 m^3 was filtered and collected.

Samples were preserved in 10 percent buffered-formalin and stored until processing in the laboratory. Water temperature, conductivity and dissolved oxygen were recorded for each entrainment sample.

Preserved entrainment samples were processed in a biological laboratory. Entrainment samples were manually sorted and eggs and larvae were identified to the lowest distinguishable taxon and enumerated. Samples with high abundances were subsampled in the laboratory using a plankton splitter such that a minimum of 200 eggs and larvae were analyzed. If numbers of eggs and larvae were low but the amount of detritus in the sample was high (more than 400 ml settled volume) then a maximum of one-half of the sample was sorted. Counts were made of the following life stages: eggs, yolk-sac larvae, post-yolk-sac larvae, and juveniles. The total length to the nearest 0.1 mm was measured for up to 30 individuals of each ichthyoplankton life stage (except eggs) per sample. If more than 30 ichthyoplankton larvae were present in a sample, a random selection of 30 specimens was measured.

Identification of fish eggs and larvae is difficult and some taxa were left unidentified or were identified only to the family level.[1] For the purposes of the economic evaluation, unidentified taxa were assigned to specific taxa based on the relative abundance of taxa that could be identified and on the relative abundance of fish species in impingement samples.[2] Estimates of entrainment per unit volume sampled for each species were scaled up to annual estimates of total entrainment using actual cooling water flow at the facility (Table 2-1).

Impingement Monitoring

Impingement sampling was conducted at the Unit 1 and Unit 2 intakes beginning on 29 June 2005 and continuing for two years through 28 June 2007 (NAI 2007). Impingement sampling was conducted one day per week from late-June 2005 through mid-December of 2005 (25 sampling weeks), from mid-March of 2006 through November of 2006 (34 sampling weeks), and from mid-March of 2007 through the end of June 2007 (15 sampling weeks). During the intervening time periods, 24-hour impingement samples were collected one day evey other week (14 sampling weeks). Weekly impingement sampling consisted of one 24-hour sample followed by one 6-day sample, and biweekly sampling consisted of one 24-hour sample followed by one 13-day sample. The 24-hour impingement samples are considered the primary sampling units, and "long interval" samples of six or 13 days are considered secondary sampling units that were useful in obtaining a full species list.

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[1] Some eggs and larvae were not identified. In such cases, species was assigned based on relative abundance of identified species and relative abundance in impingement samples.

[2] Spottail shiner spp. indicates spottail shiner and related minnow species. Bluegill spp. indicates bluegill and related sunfish species.

Impingement sampling was conducted by placing a basket in the screen wash sluiceway of Unit 1 and Unit 2 to catch all fish and debris washed off of the operating traveling screens during the sampling interval. The basket mesh was constructed from the same mesh as the traveling screens, i.e., standard 3/8-inch square stainless-steel wire. The baskets were placed in sampling position and removed using a davit and chain fall installed and operated specifically for impingement sampling.

Water quality parameters were recorded at both the Unit 1 and Unit 2 intakes. Temperature, dissolved oxygen, and conductivity were measured using calibrated electronic meters at the water's surface.

Impingement collection efficiency was determined during one 24-hour sampling period in each month to adjust each 24-hour sample for fish that are lost between the time they are impinged on the operating intake screens and their collection in the sampling device. A lot of 100 stained dead fish, representative of the species and size range that had been observed in impingement samples during the previous sampling events, was introduced immediately in front of a randomly selected operating intake screen at each unit. Fish for release were placed in an injection tank located on the deck of each unit's CWIS and flushed through a flexible 3-inch hose with running water. The discharge end of the hose released test fish at mid-depth below the surface and immediately in front of a stationary screen near the mid-point of the 24-hour collection interval. Collection efficiency test fish were recovered during the next screen wash for each unit.

Stained fish were removed from debris the following day. The number of stained fish subsequently recovered in the collection device at the end of the sampling period, divided by the number released, represents the impingement collection efficiency for that period. These impingement collection efficiency factors were applied to other 24-hour impingement collections from each period centered on the date of the collection efficiency test. Collection efficiency adjustments were not applied to the "long interval" samples.

Impingement survival studies also were conducted but these were for planning purposes to estimate what survival might be if a fish return system were installed in the future.

Impinged fish and debris were taken in fresh condition to the processing trailer located on-site at the facility and were analyzed immediately. All fish were identified to species and enumerated. A maximum of 50 individuals per species per sample were measured to the nearest millimeter total length and weighed to the nearest gram. Any individual fish that could not be identified to species in the field was taken to the laboratory for taxonomic identification by microscopic examination.

Estimates of weekly or bi-weekly impingement at the facility used in this assessment were computed from counts per unit circulator pump flow (adjusted for sampling efficiency) using actual circulator flow during the weekly or bi-weekly. The initial weekly and biweekly estimates were interpolated to mean monthly estimates, which were summed to provide an annual estimate. All impinged organisms were assumed to be killed. Monthly and annual estimates of total impingement mortality for each species that was collected are provided in Table 2-2.

SELECTION OF TARGET SPECIES

It is not practical or necessary to consider all species impinged in an economic valuation study. Sufficient information does not exist to conduct the assessment for some species and many of the species found in entrainment and impingement monitoring are found in very small numbers. Therefore, economic assessments are typically conducted using a subset of species, which for this assessment are called "Target Species". Target Species are most commonly selected to include contributors to all economic benefits categories including recreational and, where appropriate, commercial fishing as well as forage species and to be representative of the total species list entrained and impinged. In addition, ideally these Target Species should account for a large portion of total annual entrainment and impingement at the facility being addressed.

Based on a careful review of the annual entrainment and impingement estimates, 11 fish species were selected to be the focus of this report:

- Black crappie
- Bluegill
- Brown bullhead
- Largemouth bass
- Pumpkinseed
- Rainbow smelt
- Smallmouth bass
- Spottail shiner
- White sucker
- Yellow bullhead
- Yellow perch

These 11 species were selected as they are both representative of species typically entrained or impinged at Merrimack and of each of the economic benefits categories. In addition, sufficient information exists on each of these species for a technically-sound estimate of economic valuation.

For entrainment, fish larvae are difficult to identify to species, rather they were identified to groups of similar species that corresponded with the species that were impinged. Cyprinid species were assigned to spottail shiner and sunfish species were assigned to bluegill. Other species groups were presumed to correspond to the listed species listed but they likely contained other closely related species. Together, these 11 species and species groups accounted for approximately 91.9 percent of total annual entrainment and 89.4 percent of total annual impingement at Merrimack.

No federally listed threatened or endangered species and no state listed rare species or species of special concern were identified in entrainment or impingement sampling.

Table 1-1. Estimated Annual Entrainment and Species and Life-stage Assignments at Merrimack Based on Samples Collected in 2006 and 2007

Taxon	Life Stage						
	Egg	Yolk-sac larvae	Post Yolk-Sac Larvae	Entrainable Juveniles	Larva/Juv. Stage Undet.	Total	Percent
Herring family	0	0	8,536	0	0	8,536	0.28
Spottail shiner spp. [a]	7,366	119,500	725,535	12,866	0	865,266	28.66
White sucker	0	0	1,246,213	12,866	0	1,259,079	41.71
Brown bullhead	0	0	34,143	0	0	34,143	1.13
Margined madtom	0	0	17,071	6,433	0	23,504	0.78
Bluegill spp. [b]	0	31,508	315,082	0	0	346,591	11.48
Rock bass	0	0	42,679	0	0	42,679	1.41
Black crappie	0	2,635	26,346	0	0	28,980	0.96
Yellow perch	0	0	239,000	0	0	239,000	7.92
Tessellated darter	0	34,143	34,143	0	0	68,286	2.26
Unidentified	22,098	0	0	0	80,779	102,876	3.41
Total	29,464	187,785	2,688,747	32,165	80,779	3,018,939	100.00%

[a] Spottail shiner spp. indicates spottail shiner and related minnow species.
[b] Bluegill spp. indicates bluegill and related sunfish species.

Table 1-2. Mean Monthly Estimates of Total Impingement Numbers at Merrimack Based on Samples Collected from June 2005 to June 2007

Species	Total Impingement Numbers													
	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Total	Percent
American eel	0	0	0	0	0	0	0	0	8	1	0	0	9	0.26
Golden shiner	8	9	0	0	0	4	0	11	0	17	21	4	73	2.25
Spottail shiner	0	14	0	0	5	21	143	35	36	14	0	0	267	8.21
Fallfish	0	0	0	0	0	0	3	27	0	0	0	0	29	0.89
White sucker	3	6	0	0	0	0	0	0	0	0	0	0	9	0.27
Yellow bullhead	0	6	0	0	0	0	0	0	0	7	0	0	13	0.38
Brown bullhead	8	6	0	0	0	0	0	0	0	0	0	0	14	0.43
Margined madtom	22	6	0	0	6	0	0	8	0	22	23	12	97	2.99
Chain pickerel	0	0	0	0	0	0	0	8	0	0	0	0	8	0.25
Rainbow smelt	0	0	0	0	0	2	38	19	35	0	0	0	93	2.86
White perch	0	0	0	0	0	3	2	5	1	0	0	0	11	0.32
Rock bass	5	2	0	0	0	1	5	0	0	0	0	0	12	0.38
Banded sunfish	0	0	0	0	0	0	0	0	0	0	12	6	18	0.55
Redbreast sunfish	1	0	0	7	0	0	0	0	0	4	1	4	15	0.47
Pumpkinseed	21	0	0	0	42	12	9	0	0	4	0	35	122	3.77
Bluegill	1,384	99	14	16	37	43	47	8	0	23	5	130	1,804	55.56
Sunfish family	20	10	0	7	0	0	0	0	0	0	1	6	43	1.31
Smallmouth bass	1	6	10	0	0	4	4	0	4	5	0	0	33	1.00
Largemouth bass	10	13	0	0	62	55	14	2	15	2	0	0	172	5.29
Black crappie	9	0	0	21	59	50	19	4	0	0	21	37	218	6.72
Tessellated darter	0	5	0	0	0	0	0	0	0	24	2	0	30	0.92
Yellow perch	17	0	0	0	0	9	60	16	8	41	2	9	159	4.91
Total	1,511	179	24	50	210	202	341	141	106	161	86	241	3,247	100.00

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ESTIMATES OF TARGET SPECIES EQUIVALENT LOSSES

In order to calculate economic value of entrainment and impingement at Merrimack, estimates of the number of individuals entrained and impinged for the Target Species must be converted to equivalent measures that can be assigned economic value for these species. For species of commercial and/or recreational importance, the equivalent measure selected was the yield to the fishery that would have been expected had the individuals not been entrained or impinged. For species that serve as forage for other, generally larger, aquatic organisms, the measure selected was the production of biomass available as food for higher trophic levels that would have been expected had the individuals not been entrained or impinged. Methods used in this report to calculate these two measures are consistent with those used by USEPA in the Phase II (USEPA 2004b) and Phase III (USEPA 2006) rulemaking efforts and are described below.

The measure "yield to the fishery" is defined as the total yield (in weight) that could have occurred in the commercial or recreational fishery from those individuals lost to entrainment or impingement in the absence of compensatory changes in total mortality. This yield is calculated using the Equivalent Yield Model (EYM), which integrates Baranov's catch equation (Ricker 1975) with estimates of the mean weight by age (Dey 2002, EPRI 2004). This method is conservative in that potential density-dependent changes in mortality or growth rates that often occur in natural populations were not included. Using the EYM, equivalent yield for each Target Species from entrainment and impingement was estimated as follows:

$$EY = \sum_{i=1}^{n_f}\left[\sum_{j=1}^{n_l}\left(NL_j S_{j\rightarrow i}\right) A_i W_i \frac{V_i F_i}{Z_i}\right]$$

where:

EY	=	Equivalent yield to fishery
NL_j	=	Number of each Stage or Age Category (j) lost to entrainment and impingement at the facility
$S_{j\rightarrow i}$	=	Total survival from Stage or Age Category (j) to Age (i)
n_j	=	Number of Stage or Age Category (j) entrained or impinged at the facility
V_i	=	Fraction of Stage or Age Category (i) vulnerable to fishing
F_i	=	Instantaneous fishing mortality rate for Stage or Age Category (i)
Z_i	=	Instantaneous total mortality rate for Stage or Age Category (i)
A_i	=	Total mortality rate for Stage or Age Category (i) = $1-e^{-Z_i}$

W_i	=	Average weight for individual of Stage or Age Category (i) captured in the fishery
n_f	=	Maximum number of Stage or Age categories vulnerable to fishery.

The EYM results in an estimate of yield defined in the same units used to describe the average weight of the individuals and integrates yield across all ages. In this assessment, the EYM was applied to each of the Target Species that support either commercial or recreational fishing.

The measure of biomass production that could have resulted from species impinged or entrained at each facility was calculated using the Production Foregone Model (PFM) (Dey 2002, EPRI 2004). As with the EYM, this method is also conservative in that potential density-dependent changes in mortality or growth rates that often occur in natural populations were not included. Using the PFM, potential biomass production from entrainment and impingement was estimated for each of the Target Species as follows:

$$P_i = \sum_{i=1}^{L} \frac{\sum_{j=1}^{n_l} \left(NL_j S_{j \to i}\right) G_i W_i \left(e^{(G_i - Z_i)} - 1\right)}{G_i - Z_i}$$

and the total production foregone (P) can be found by summing over all the age categories that are entrained or impinged:

$$P = \sum_{i=1}^{m} P_i$$

where:

P	=	Total production foregone
P_i	=	Production foregone for individuals entrained or impinged at each facility in Stage or Age Category (i)
G_i	=	Instantaneous growth rate in weight for Stage or Age Category (i)
NL_j	=	Number of each Stage or Age Category (j) lost to entrainment or impingement at the facility
$S_{j\to i}$	=	Total survival from Stage or Age Category (j) to Age (i)
n_j	=	Number of Stage or Age categories entrained or impinged at the facility
W_i	=	Average weight of individuals in Stage or Age Category (i)
Z_i	=	Instantaneous mortality rate for Life Stage or Age Category (i)
m	=	Total number of age categories entrained or impinged at the facility
L	=	Final age category.

The PFM was applied to all Target Species that as individuals serve as food for other aquatic organisms during at least part of their life cycle.

Additionally, relationships among the key inputs to the EYM and PFM are as follows:

$$Z_i = M_i + F_i$$

$$A_i = 1 - e^{-Z_i}$$

$$S_{j \to i} = 1 - \prod_{i=j}^{r} (1 - A_i)$$

$$G_i = \ln\left(\frac{BW_{i+1}}{BW_i}\right)$$

$$W_i = BW_i e^{G_i \overline{T}_i}$$

where:

M_i	=	Instantaneous natural mortality rate for Stage or Age Category (i)
BW_i	=	Average weight of individuals at the beginning of Stage or Age Category (i)
BW_i	=	Average weight of individuals at the beginning of Stage or Age Category (i+1)
$S_{j \to i}$	=	Total survival from Stage or Age Category (j) to Age (i)
r	=	Total number of age categories between Age Category (j) and Age Category (i)
$\overline{T}_i$	=	Median fraction of Stage or Age Category (i) completed
		$\frac{\log(2) - \log(1 + e^{-Z_i})}{Z_i} = \frac{\log(2) - \log(1 + e^{-Z_i t_i})}{Z_i}$
t_i	=	Duration of Stage or Age Category (i).

More information on these inputs and relationships can be found in Ricker (1975). Estimation of the biological input parameters for each of the Target Species is described below.

ASSIGNMENT OF AGE CATEGORIES FOR IMPINGED INDIVIDUALS

One of the necessities of equivalent loss calculation is that the direct measures of impingement mortality must be assigned to individual age categories as defined in the production foregone and equivalent yield models. For this assessment, age was assigned using length information for each Target Species obtained from impingement monitoring conducted at the facility, together with estimates of length at age for these same species obtained from the scientific literature and from an analysis of the length frequency patterns for each species. Details are provided in Appendix A.

Life Table Information

Biological input parameters for the Production Foregone and Equivalent Yield models include life stage durations, instantaneous natural and fishing mortality rates, and the fraction vulnerable to the fishery for each life stage and age, as well as mean weights at the beginning of each life stage and age for each Target Species. Each of these model inputs were determined as described below.

Life Stage Durations

Estimates of life stage durations for entrainable life stages of each target species were based on information provided in EPRI (2005) and EPRI (In preparation). For some species, duration information was only available for the total larval period, hence, best professional judgment was used to develop estimated durations for the two larval stages. Median life-stage durations for each target species used in this assessment are:

Entrained Taxon	Life Stage Duration (Days)			
	Egg	Yolk-sac larvae	Post Yolk-Sac Larvae	Entrainable Juveniles
Black crappie	2	4	36	40
Bluegill	6	4	20	31
Brown bullhead	8	9	14	29
Largemouth bass	6	10	7	40
Pumpkinseed	6	4	20	31
Rainbow smelt	20	4	86	10
Smallmouth bass	6	10	7	40
Spottail shiner	6	4	36	10
White sucker	4	8	38	7
Yellow bullhead	8	9	14	29
Yellow perch	6	8	17	10

Estimates of impingement on a monthly basis were developed for this assessment. Consequently, the duration of each month was set as 30.4 days, the average monthly duration across the entire year. However, it is important to recognize that fish do not become vulnerable to impingement until they are approximately 1 inch long and typically 1 to 2 months of age on a traditional 3/8-inch mesh traveling screen. Hence, the number of months remaining in the first year of life is normally less than 12. The number of whole months of impingement vulnerability during Age 0 was determined by dividing the total time between the median date of initial impingement vulnerability and the end of the first year of life by the average month duration (30.4 days). Any remainder was assigned as the duration of the first month of impingement vulnerability. Median date of initial impingement vulnerability for each target species, shown below, was determined using best professional judgment:

Taxon	Median Month of Initial Impingement Vulnerability
Black crappie	Sep
Bluegill	Sep
Brown bullhead	Jul
Largemouth bass	Aug
Pumpkinseed	Sep
Rainbow smelt	Aug
Smallmouth bass	Aug
Spottail shiner	Sep
White sucker	Jun
Yellow bullhead	Jul
Yellow perch	May

In this assessment, we assumed that all individuals entrained or impinged in each age category were at the median age for that category. The median age is the age at which half of the individuals in that age category were older than the median age while the remaining half were younger. Median age for each age category was calculated as:

$$d_i = \frac{\ln 2 - \ln(1+e^{-Z_i t_i})}{Z_i}$$

where:

d_i = median age of Stage or Age Category (i)

t_i = duration (days) for Stage or Age Category (i).

Natural Mortality Rates

In this assessment natural mortality refers to any source of death other than through fishing or entrainment and impingement. In aquatic ecosystems, the ultimate cause of death, especially in the early stages of fish, is principally through predation. For calculation of production foregone, it was assumed that all natural mortality is a result of being consumed by predators.

A range (maximum, most probable, and minimum) of instantaneous natural mortality rates for each target species was obtained from the following sources:

Black crappie – Most probable daily instantaneous natural mortality rates for eggs, yolk-sac larvae, and post yolk-sac larvae were obtained from EPRI (2005) Table 4-41. Maximum and minimum values were assumed to be 25 percent higher and 25 percent lower than the most probable value, respectively. Maximum and minimum daily instantaneous natural mortality rates for juvenile and older fish were obtained from EPRI (2005) Table 4-41, and the most probable rate was assumed to be the midpoint between the maximum and minimum values.

Bluegill – Most probable daily instantaneous natural morality rates were obtained from EPRI (In preparation). Maximum and minimum values were assumed to be 25 percent higher and 25 percent lower than the most probable value, respectively.

Brown bullhead – Most probable daily instantaneous natural morality rates were obtained from EPRI (In preparation). Maximum and minimum values were assumed to be 25 percent higher and 25 percent lower than the most probable value, respectively.

Largemouth bass – Most probable daily instantaneous natural morality rates were obtained from EPRI (In preparation) for smallmouth bass. Maximum and minimum values were assumed to be 25 percent higher and 25 percent lower than the most probable value, respectively.

Pumpkinseed – Most probable daily instantaneous natural morality rates were obtained from EPRI (In preparation) for bluegill as a surrogate. Maximum and minimum values were assumed to be 25 percent higher and 25 percent lower than the most probable value, respectively.

Rainbow smelt – Most probable daily instantaneous natural mortality rates for eggs, yolk-sac larvae, and post yolk-sac larvae were obtained from EPRI (2005) Table 4-37. Maximum and minimum values were assumed to be 25 percent higher and 25 percent lower than the most probable value, respectively. Most probable, maximum, and minimum daily instantaneous natural mortality rates for entrainable juveniles were obtained from EPRI (2005) Table 4-37. Maximum and minimum daily instantaneous natural mortality rates for impingeable juveniles and for older fish were obtained from EPRI (2005) Table 4-37, and the most probable value was assumed to be the midpoint between the maximum and minimum values.

Smallmouth bass – Most probable daily instantaneous natural morality rates were obtained from EPRI (In preparation). Maximum and minimum values were assumed to be 25 percent higher and 25 percent lower than the most probable value, respectively.

Spottail shiner – Most probable daily instantaneous natural morality rates were obtained from EPRI (In preparation) for a “generic” minnow or shiner species. Maximum and minimum values were assumed to be 25 percent higher and 25 percent lower than the most probable value, respectively.

White sucker — Most probable daily natural morality rates were obtained from EPRI (In preparation) for shorthead redhorse as a surrogate. Maximum and minimum values were assumed to be 25 percent higher and 25 percent lower than the most probable value, respectively.

Yellow bullhead – Most probable daily instantaneous natural morality rates were obtained from EPRI (In preparation) for brown bullhead. Maximum and minimum values were assumed to be 25 percent higher and 25 percent lower than the most probable value, respectively.

Yellow perch – Most probable, maximum, and minimum daily instantaneous natural mortality rates for eggs, yolk-sac larvae, and post yolk-sac larvae were obtained from EPRI (2005) Table 4-39. Maximum and minimum daily instantaneous natural mortality rates for impingeable juveniles and for older fish were obtained from EPRI (2005) Table 4-39, and the most probable value was assumed to be the midpoint between the maximum and minimum values.

Fishing Mortality Rates

Fishing mortality refers to the death of individuals as a result of commercial, recreational and/or subsistence fishing. In this assessment, fishing mortality was assumed to apply only to those 10 target taxa subject to fishing (black crappie, bluegill, brown bullhead, largemouth bass, pumpkinseed, rainbow smelt, smallmouth bass, white sucker, yellow bullhead, and yellow perch). One taxon, spottail shiner, was assumed not to be harvested by fishermen.

A range (maximum, most probable, and minimum) of instantaneous fishing mortality rates for all 10 target taxa subject to fishing were selected as follows:

<u>Black crappie</u> – Most probable daily instantaneous fishing morality rates were assumed to be one-half of the total annual mortality rate, which was obtained from EPRI (In preparation), and equal to the natural mortality rate.

<u>Bluegill</u> – Most probable daily instantaneous fishing morality rates were obtained from EPRI (In preparation). Maximum and minimum values were assumed to be 25 percent higher and 25 percent lower than the most probable value, respectively.

<u>Brown bullhead</u> – Most probable daily instantaneous fishing morality rates were obtained from EPRI (In preparation). Maximum and minimum values were assumed to be 25 percent higher and 25 percent lower than the most probable value, respectively.

<u>Largemouth bass</u> – Most probable daily instantaneous fishing morality rates were assumed to be one-half of the total annual mortality rate, which was obtained from EPRI (In preparation) for smallmouth bass, and equal to the natural mortality rate.

<u>Pumpkinseed</u> – Most probable daily instantaneous fishing morality rates were obtained from EPRI (In preparation) for bluegill as a surrogate. Maximum and minimum values were assumed to be 25 percent higher and 25 percent lower than the most probable value, respectively.

<u>Rainbow smelt</u> – Most probable daily instantaneous fishing morality rates were assumed to be one-half of the total annual mortality rate, which was obtained from EPRI (In preparation), and equal to the natural mortality rate.

<u>Smallmouth bass</u> – Most probable daily instantaneous fishing morality rates were assumed to be one-half of the total annual mortality rate, which was obtained from EPRI (In preparation), and equal to the natural mortality rate.

<u>White sucker</u> – Most probable daily fishing morality rates were obtained from EPRI (In preparation) for shorthead redhorse as a surrogate. Maximum and minimum values were assumed to be 25 percent higher and 25 percent lower than the most probable value, respectively.

<u>Yellow bullhead</u> – – Most probable daily instantaneous fishing morality rates were obtained from EPRI (In preparation) for brown bullhead. Maximum and minimum values were assumed to be 25 percent higher and 25 percent lower than the most probable value, respectively.

Yellow perch – Most probable daily instantaneous fishing mortality rates were assumed to be one-half of the total annual mortality rate obtained from EPRI (2005) Table 4-39, and equal to the natural mortality rate. Maximum and minimum values were assumed to be 25 percent higher and 25 percent lower than the most probable value, respectively.

Fishing Vulnerability Rates

Fishing vulnerability rates refer to the fraction of each age at a size vulnerable to be harvested by anglers. For the maximum and minimum fishing vulnerability rates used in this assessment, individuals were assumed to be not vulnerable (rate = 0) up to a set age and completely vulnerable (rate = 1) above that age. The ages of complete vulnerability were estimated using best professional judgment based on length at age information from the scientific literature and current fishing regulations. Resulting estimates are as follows:

	Age at Initial Fishing Vulnerability (Years)	
Species	**Earliest**	**Latest**
Black crappie	3	7
Bluegill	3	7
Brown bullhead	2	3
Largemouth bass	4	7
Pumpkinseed	3	7
Rainbow smelt	2	3
Smallmouth bass	4	7
White sucker	1	2
Yellow bullhead	2	3
Yellow perch	2	4

The maximum vulnerability was assigned using the earliest age whereas the minimum vulnerability was assigned using the latest age. The most probable values were assigned assuming that half of the population became vulnerable at the age of maximum initial vulnerability while the remaining half became vulnerable at the age of minimum initial vulnerability. These most probable values were used to provide the best estimates of equivalent loss.

Weight at Beginning of Age

This input parameter refers to the average weight of individuals as they enter each age category. These weights are then used to determine the average weight of harvested individuals for calculation of equivalent fishery yield and to determine the daily instantaneous growth rate used for calculation of production foregone.

A range (maximum, most probable, and minimum) of estimated weights at the beginning of each age were obtained for each target species from the following sources:

Black crappie –Most probable mean weights (g) for each life stage for eggs, yolk-sac larvae, and post yolk-sac larvae were obtained from EPRI (2005) Table 4-41. Maximum and minimum values were assumed to be 20 percent higher and 20 percent lower than the most probable value, respectively. Maximum and minimum mean weights (g) at the beginning of each age for juvenile and older fish were obtained from EPRI (2005) Table 4-41, and the most probable rate was assumed to be the midpoint between the maximum and minimum values.

Bluegill – Most probable mean weights (g) at the beginning of each age were obtained from EPRI (In preparation). Maximum and minimum values were assumed to be 20 percent higher and 20 percent lower than the most probable value, respectively.

Brown bullhead – Most probable mean weights (g) at the beginning of each age were obtained from EPRI (In preparation). Maximum and minimum values were assumed to be 20 percent higher and 20 percent lower than the most probable value, respectively.

Largemouth bass – Most probable mean weights (g) at the beginning of each age were obtained from EPRI (In preparation) for smallmouth bass. Maximum and minimum values were assumed to be 20 percent higher and 20 percent lower than the most probable value, respectively.

Pumpkinseed – Most probable mean weights (g) at the beginning of each age were obtained from EPRI (In preparation) for bluegill. Maximum and minimum values were assumed to be 20 percent higher and 20 percent lower than the most probable value, respectively.

Rainbow smelt – Most probable mean weights (g) of eggs, larvae, entrainable juveniles were obtained from EPRI (2005) Table 4-37. Maximum and minimum values for the egg through age-0 juvenile life stages were assumed to be 20 percent higher and 20 percent lower than the most probable value, respectively. For age-1 and older fish, the maximum and minimum mean weights at the beginning of each age were obtained from EPRI (2005) Table 4-37, and the most probable value was assumed to be the average of the maximum and minimum weights.

Spottail shiner – Most probable mean weights (g) at the beginning of each age were obtained from EPRI (In preparation) for a "generic" shiner or minnow. Maximum and minimum values were assumed to be 20 percent higher and 20 percent lower than the most probable value, respectively.

Smallmouth bass – Most probable mean weights (g) at the beginning of each age were obtained from EPRI (In preparation). Maximum and minimum values were assumed to be 20 percent higher and 20 percent lower than the most probable value, respectively.

White sucker – Most probable mean weights (g) at the beginning of each age were obtained from EPRI (In preparation) for shorthead redhorse. Maximum and minimum values were assumed to be 20 percent higher and 20 percent lower than the most probable value, respectively.

Yellow bullhead – Most probable mean weights (g) at the beginning of each age were obtained from EPRI (In preparation) for brown bullhead. Maximum and minimum values were assumed to be 20 percent higher and 20 percent lower than the most probable value, respectively.

Yellow perch – Most probable mean weights (g) of eggs, larvae, and entrainable juveniles were obtained from EPRI (2005) Table 4-39. Maximum and minimum values for the egg through age-0 juvenile life stages were assumed to be 20 percent higher and 20 percent lower than the most probable value, respectively. For age-1 and older fish, the maximum and minimum mean weights at the beginning of each age were obtained from EPRI (2005) Table 4-39, and the most probable value was assumed to be the average of the maximum and minimum weights.

For all species, weights at the beginning of each month within an age were interpolated using an instantaneous growth rate based on the weights at the beginning and end of that age. The most probable values were used to provide the best estimates of equivalent loss.

Equivalent Loss Estimates

Annual fishery yield equivalent to the current entrainment and impingement losses at Merrimack totaled 313 lb for entrainment and 97 lb for impingement under actual cooling water flows (Table 3-1). Most (>73 percent) of this equivalent yield was attributed to just two species, white sucker and yellow perch.

Annual production foregone equivalent to the current entrainment and impingement losses at Merrimack totaled 2,160 lb for entrainment and 222 lb for impingement under actual cooling water flows (Table 3-2). Most (> 83 percent) of this production foregone was attributed to three species, white sucker, yellow perch and brown bullhead.

Equivalent Predator

Any potential production increase would be transferred to several predator species, including some species with little or no recreational or commercial importance. It would be reasonable and conservative to assume that the potential production increase would be consumed by largemouth bass, a popular target of recreational fisherman in the region.

A trophic transfer coefficient of 10 percent, consistent with USEPA (2004b), could be used to convert the total biomass foregone to the amount of higher trophic level biomass supportable by that production foregone. The coefficient means that an average of 10 percent of the production foregone would have ended up as predator biomass.

An annual exploitation rate of 25 percent could be used to estimate impacts on fishing harvests for the equivalent predator. Based on the estimated total production foregone of 2,382 lbs (Table 3-2), the trophic transfer coefficient of 10 percent, and the exploitation rate of 25 percent, the estimated baseline impact on largemouth bass harvest is 60 lbs. Accounting for other species that suffer I&E at Merrimack Station beyond the 11 target species considered here would slightly increase the estimated baseline impact on largemouth bass harvest.

Table 2-1 Estimates of Total Annual Equivalent Fishery Yield (lb) for each Target Species Equivalent to Entrainment and Impingement Losses at Merrimack

Taxa	Total Annual Equivalent Fishery Yield (lb)		
	Entrainment	Impingement	Combined
Black crappie	1	14	16
Bluegill type	0	39	39
Brown bullhead	29	2	30
Largemouth bass	0	8	8
Pumpkinseed	0	3	3
Rainbow smelt	0	1	1
Smallmouth bass	0	9	9
Spottail shiner[a]	0	0	0
White sucker	163	3	165
Yellow bullhead	0	2	2
Yellow perch	119	17	136
Total	313	97	410

[a] This species directly supports no commercial or recreational fisheries. Its value is indirect as forage to support other predator species.

Table 2-2 Estimates of Total Annual Production Foregone (lb) for each Target Species Equivalent to Entrainment and Impingement at Merrimack

Taxa	Total Annual Production Foregone (lb)		
	Entrainment	Impingement	Combined
Black crappie	6	36	41
Bluegill type	8	96	104
Brown bullhead	251	4	254
Largemouth bass	0	25	25
Pumpkinseed	0	6	6
Rainbow smelt	0	2	2
Smallmouth bass	0	16	16
Spottail shiner	187	0	187
White sucker	1,253	4	1,257
Yellow bullhead	0	3	3
Yellow perch	455	30	485
Total	2,160	222	2,382

3

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A

APPENDIX A: ESTIMATION OF AGE COMPOSITION FOR IMPINGED FISH

Age composition of impinged fish was estimated from length data. Cut-point lengths between ages were set mid-way between the mean lengths of successive age classes. The process is illustrated for a hypothetical example in Figure A-1. Note that even though length distributions are highly overlapping this approach yields reasonable estimates. These cut-points were first estimated for the month of annulus formation. Cut-points for other months were interpolated by eye. The upper cut-points used to designate each age group are provided in Table A-1; the assigned ages are in Table A-2.

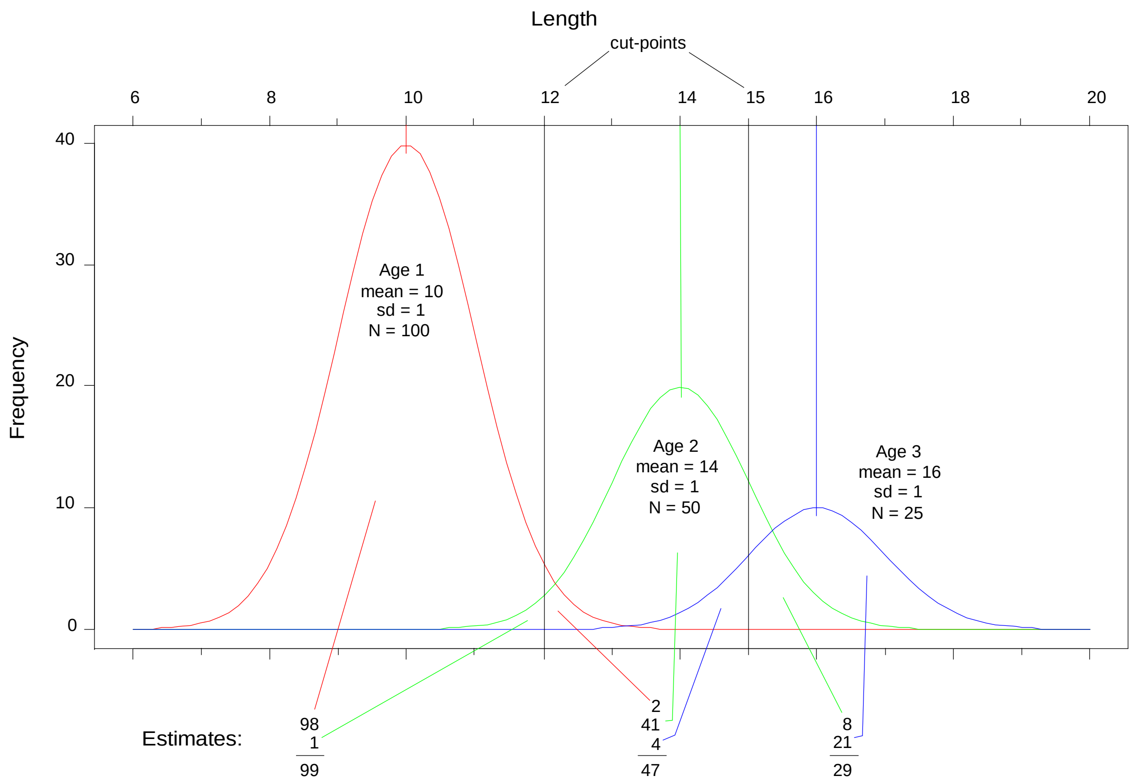

Figure A-1. Method of Setting Cut-point Halfway Between Mean Lengths for a Plausible Hypothetical Example

Table A-1. Spawning Month for Target Species and Associated Cut-points for Age Classes

Age	Spottail shiner	White sucker	Yellow bullhead	Brown bullhead	Rainbow smelt	Bluegill
	May	May	June	June	May	June
1	70	81	90	90	124	78
2	98	153	140	165	165	116
3	112	219	190	212	>165	146
4	121	268	229	249		170
5	>121	322	>229	>249		194
6		351				>194
7		369				
8		>369				

Age	Pumpkinseed	Smallmouth bass	Largemouth bass	Black crappie	Yellow perch
	June	June	June	June	May
1	78	125	125	78	100
2	89	257	197	146	149
3	122	355	267	200	180
4	148	>355	334	243	196
5	144		391	263	211
6	>144		408	>263	264
7			432		275
8			449		>275
9			>449		

Table A-2. Assigned Age-frequency Distributions Based on Length Frequencies for Target Species at Merrimack from June 2005 to June 2007

Age	Age Frequency					
	Spottail shiner	White sucker	Yellow bullhead	Brown bullhead	Rainbow smelt	Bluegill
0	15.58	0.00	0.00	0.00	100.00	12.10
1	18.50	0.00	0.00	79.92	0.00	82.14
2	23.96	0.00	48.00	0.00	0.00	3.35
3	28.67	0.00	52.00	20.08	0.00	1.07
4	6.74	0.00	0.00	0.00	0.00	0.82
5	6.55	0.00	0.00	0.00	0.00	0.00
6	0.00	0.00	0.00	0.00	0.00	0.52
7	0.00	0.00	0.00	0.00	0.00	0.00
8	0.00	100.00	0.00	0.00	0.00	0.00
Sum	100.00	100.00	100.00	100.00	100.00	100.00

Age	Pumpkinseed	Smallmouth bass	Largemouth bass	Black crappie	Yellow perch
0	19.13	26.32	91.39	63.29	5.99
1	31.05	40.35	8.61	36.71	55.03
2	36.68	0.00	0.00	0.00	22.84
3	13.14	16.67	0.00	0.00	11.54
4	0.00	0.00	0.00	0.00	1.55
5	0.00	16.67	0.00	0.00	0.00
6	0.00	0.00	0.00	0.00	3.06
7	0.00	0.00	0.00	0.00	0.00
8	0.00	0.00	0.00	0.00	0.00
Sum	100.00	100.00	100.00	100.00	100.00