Chapter A5: Methods Used to Evaluate I&E

Introduction

This chapter describes the methods used by EPA to evaluate facility impingement and entrainment (I&E) data. Section A5-1 discusses the main objectives of EPA's I&E evaluation. Section A5-2 describes EPA's general approach to modeling fishery yield, the primary focus of its analysis, and the rationale for this approach. Section A5-3 describes the source data for EPA's I&E evaluations. Section A5-4 presents details of the biological models used to evaluate I&E. Finally, section A5-5 discusses methods used to extrapolate I&E rates from facilities evaluated to other facilities in the same region.

Chapter Contents

A5-1 Objectives of EPA's Evaluation of I&E Data

EPA's evaluation of I&E data had four main objectives:

- to develop a national estimate of the magnitude of I&E,
- to standardize I&E rates using common biological metrics so that rates could be compared across species, years, facilities, and geographical regions,
- to estimate changes in these metrics as a result of projected reductions in I&E under the Phase II rule, and
- to estimate the national economic benefits of reduced I&E.

Three loss metrics were derived to standardize I&E loss rates of all life stages: (1) foregone age-1 equivalents, (2) foregone fishery yield, and (3) foregone biomass production. The methods used to calculate these metrics are described in section A5-4. Age-1 equivalent estimates were used to quantify losses of individuals in terms of a single life stage. Losses of commercial and recreational species were expressed as foregone fishery yield. Estimates of production foregone were used to quantify the contribution of forage species to the yield of harvested species. The following section discusses EPA's rationale for evaluating the impingement and entrainment of harvested species in terms of foregone yield.

A5-2 Rationale for EPA's Approach to Evaluating I&E of Harvested Species

Harvested species were the main focus of EPA's analysis, primarily because of the availability of economic methods for valuing these species (see Chapters A9 through A14 for a discussion of all of the economic methods used by EPA to estimate benefits of the Phase II rule). EPA's approach to estimating changes in harvest assumed that I&E losses result in a reduction in the number of harvestable adults in years after the time that individual fish are killed by I&E and that future reductions in I&E will lead to future increases in fish harvest. The approach does not require knowledge of population size or the total yield of the fishery; it only estimates the incremental yield that is foregone because of the number of deaths due to I&E.

As discussed in detail in section A5-4.2, EPA's yield analysis employed a specific application of the Thompson Bell model of fisheries yield (Ricker, 1975) to assess the effects of I&E on net fish harvest. This model is a relatively simple yield-per-recruit (YPR) model that provides estimates of yield (a.k.a. "harvest" or "landed fish") that can be expected from a cohort of fish that is recruited to a fishery. The model requires estimates of size-at-age for particular species and stage-specific schedules of natural mortality (M) and fishing mortality (F). All of the key parameters used in the yield model, F, M, and size-at-age, were assumed to be constant for a given species regardless of changes in I&E rates. Because these parameters are held static for any particular fish stock, YPR is also a constant value. With this set of parameters fixed, the Thompson Bell model holds that an estimate of recruitment is directly proportional to an estimate of yield.

EPA recognizes that the assumption that the key parameters are static is an important one that is not met in reality. However, by focusing on a simple interpretation of each individual I&E death in terms of foregone yield, EPA concentrated on the simplest, most direct assessment of the potential economic value of eliminating that death. EPA believes that this approach was warranted given the (1) scope and objectives of its analysis of harvested species, (2) data available, and (3) difficulties in distinguishing the causes of population changes. Each of these factors is discussed in the following sections.

A5-2.1 Scope and Objectives of EPA's Analysis of Harvested Species

The simplicity of EPA's approach to modeling yield was consistent with the need to examine the dozens of harvested species that are vulnerable to I&E throughout the country (see Table A5-1) and the overall objective of developing regional- and national-scale estimates. This approach is not necessarily the best alternative for studies of single facilities for which site-specific details on local fish stocks and waterbody conditions might make possible the use of more complex assessment approaches, including some form of population model.

Table A5-1: Number of Facilities In Scope of Phase II, Facilities Evaluated, and Species with I&E Data in Each Region

Region	# Facilities In Scope	# Facilities Evaluated	# Species with I&E Data
California	20	18	305
North Atlantic	22	4	128
Mid-Atlantic	44	6	63
South Atlantic	16	0	N/A[a]
Gulf of Mexico	24	4	160
Great Lakes	56	3	84
Inland	358	11	106

[a] I&E estimates for this region were extrapolated from rates for Mid-Atlantic and Gulf of Mexico.

A5-2.2 Data Availability and Uncertainties

Although EPA's approach to modeling yield requires estimates of a large number of stage-specific growth and mortality parameters, the use of more complex fish population models would rely on an even larger set of significant data uncertainties and would require numerous additional and stronger assumptions about the nature of stock dynamics that would be difficult to defend with available data. Additional data uncertainties of population dynamics models include the relationship between stock size and recruitment, and how growth and mortality rates may change as a function of stock size and other factors. Obtaining this information for even one fish stock is time-consuming and resource intensive; obtaining this information for the many species subject to impingement and entrainment nation-wide was not possible for EPA's national benefits analysis.

It is also important to note that information on stock status is generally only available for harvested species, which represent less than 2% of I&E losses. Even for harvested species, stock status is often poorly known. For example, only 20 of a total of 92 distinct species that are impinged and entrained by northern California facilities are harvested species with fishery management plans, and the stock status for all but one of these is unknown or undefined (Leet et al., 2001). While the number of species with known status is better in some regions than others, a similar problem exists in all of the regions included in EPA's benefits analysis. In fact, only 23% of U.S. managed fish stocks have been fully assessed (U.S. Ocean Commission, 2002).

In addition to a lack of data, there are numerous issues and difficulties with defining the size and spatial extent of fish stocks. As a result, it is often unclear how I&E losses at particular cooling water intake structures can be related to specific stocks. For example, a recent study of Atlantic menhaden (*Brevoortia tryannus*), one of the major fish species subject to impingement and entrainment along the Atlantic Coast of the U.S., indicated that juveniles in Delaware Bay result from both local and long distance recruitment (Light and Able, 2003). Thus, accounting only for influences on local recruitment would be insufficient for understanding the relationship between recruitment and menhaden stock size.

Another difficulty is that fisheries managers typically define fish stocks by reference to the geographic scope of the fishery responsible for landings. However, landings data are reported state by state, which is generally not a good way to delineate the true spatial extent of fish populations.

A5-2.3 Difficulties Distinguishing Causes of Population Changes

Another difficulty in developing more complex models of harvested species is that it is fundamentally difficult to demonstrate that any particular kind of stress causes a reduction in fish population size. All fish populations are under a variety of stresses that are difficult to quantify and that may interact. Fish populations are perpetually in flux for numerous reasons, so determining a baseline population size, then detecting a trend, and then determining if a trend is a significant deviation from an existing baseline or is simply an expected fluctuation around a stable equilibrium is problematic. Fish recruitment is a multidimensional process, and identifying and distinguishing the causes of variance in fish recruitment remains a fundamental problem in fisheries science, stock management, and impact assessment (Hilborn and Walters, 1992; Quinn and Deriso, 1999; Boreman, 2000). This issue was beyond the scope and objectives of EPA's section 316(b) benefits analysis.

A5-3 Source Data

A5-3.1 Facility I&E Monitoring Data

The inputs for EPA's analyses included the empirical I&E monitoring expressed as counts reported by facilities and species life history characteristics such as growth rates, natural mortality rates, and fishing mortality rates. The general approach to I&E monitoring was similar at most facilities, but investigators used a wide variety of methods that were specific to the individual studies, e.g., location of sampling stations, sampling gear, sampling frequency, and enumeration techniques.

Impingement monitoring typically involves sampling impingement screens or catchment areas, counting the impinged fish, and extrapolating the count to an annual basis. Entrainment monitoring typically involves intercepting a small portion of the intake flow at a selected location in the facility, collecting fish by sieving the water sample through nets or other collection devices, counting the collected fish, and extrapolating the counts to an annual basis.

To the extent possible, EPA considered and evaluated facility-specific monitoring and reporting procedures, as described in EPA's individual regional reports (see Parts B-H of this Regional Study Assessment). EPA used life stage-specific annual losses for assessment of entrainment losses. However, in most cases, the size or life stage of impinged fish were not reported. The EPA modeling procedure requires the age (or life stage) of the killed fish. Therefore, the age of impinged fish was assumed to range from the juvenile stage to age 5, so the total impingement losses as reported were divided into age groups using proportions corresponding to the expected life table dictated by species-specific mortality schedules.

EPA adjusted annualized loss rates at some facilities as needed to reflect the history of technological changes at the facility. The purpose of the adjustments was to interpret loss records in a way that best reflects the current conditions at each facility. So, for example, if a facility was known to have installed a protective technology subsequent to the time that I&E loss rates were recorded, EPA reduced the loss rates in an amount corresponding to the presumed effectiveness of the protective technology.

Loss rates recorded at each facility were expressed as an annual average rate, regardless of the number of years of sampling data available. All information regarding species, life stage, and loss modality (I or E) was retained just as they were originally reported, with the exception of some species aggregation that is described below. The annual total among the facilities evaluated was then the subject of the detailed modeling procedure described in section A5-4. Once this analysis was completed, estimates of total losses, by region, were generated using the extrapolation procedures described in section A5-5.

A5-3.2 Species Groups Evaluated

To evaluate I&E, EPA organized species into groups and then conducted detailed analyses of I&E rates for each species group. Species groups were based on similarities in life history characteristics and the groupings used by the National Marine

Fisheries Service (NMFS) for landings data. An appendix to each regional report in Parts B-H of this document provides details on the species groups and life history data that were used.

A5-3.3 Species Life History Parameters

The life history parameters used in EPA's analysis of I&E data included species growth rates, the fraction of each age class vulnerable to harvest, fishing mortality rates, and natural (nonfishing) mortality rates. Each of these parameters was also stage-specific. For the purpose of this assessment, EPA uses the terms "age" and "stage" interchangeably. For fish age 1 and older, a stage corresponds directly to the age of the fish. For fish younger than age one, a stage corresponds to specific early life developmental stages. Early developmental stages may occur at different ages, and may have different durations for different species. All of the modeling procedures and parameterization are expressed on a stage-wise basis.

EPA obtained life history parameters from facility reports, the fisheries literature, local fisheries experts, and publicly available fisheries databases (e.g., FishBase). To the extent feasible, EPA identified region-specific life history parameters, and all I&E losses within a region were modeled with a single set of parameters. Detailed citations are provided in the life history appendix accompanying each regional report (Parts B-H of the Regional Study Document).

For most species in most regions a reasonable set of life history parameter values was identified. However, in a few cases where no information on survival rates was available for individual life stages, EPA deduced survival rates for an equilibrium population based on records of lifetime fecundity using the relationship presented in C.P. Goodyear (1978) and below in Equation (1):

$$S_{eq} = 2/fa \qquad \text{(Equation 1)}$$

where:

S_{eq} = the probability of survival from egg to the expected age of spawning females
fa = the expected lifetime total egg production

Published fishing mortality rates (F) were assumed to reflect combined mortality due to both commercial and recreational fishing. Basic fishery science relationships (Ricker, 1975) among mortality and survival rates were assumed, such as:

$$Z = M + F \qquad \text{(Equation 2)}$$

where:

Z = the total instantaneous mortality rate
M = natural (nonfishing) instantaneous mortality rate
F = fishing instantaneous mortality rate

and

$$S = e^{(-Z)} \qquad \text{(Equation 3)}$$

where:

S = the survival rate as a fraction

A5-4 Methods for Evaluating I&E

The methods used to express I&E losses in units suitable for economic valuation are outlined in Figure A5-1 and described in detail

A5-4.1 Modeling Age 1 Equivalents

The Equivalent Adult Model (EAM) is a method for expressing I&E losses as an equivalent number of individuals at some other life stage, referred to as the age of equivalency (Horst 1975a; C.P. Goodyear, 1978; Dixon, 1999). The age of equivalency can be any life stage of interest. The method provides a convenient means of converting losses of fish eggs and larvae into units of individual fish and provides a standard metric for comparing losses among species, years, and regions. For the section 316(b) regional case studies, EPA expressed I&E losses at all life stages as an equivalent number of age 1 individuals.

The EAM calculation requires life-stage-specific impingement and entrainment counts and life-stage-specific mortality rates from the life stage of impingement or entrainment to the life stage of equivalence. The cumulative survival rate from age at impingement or entrainment until age 1 is the product of all stage-specific survival rates to age 1. For impinged fish that are older than age 1, age 1 equivalents are calculated by modifying the basic calculation to inflate the loss rates in inverse proportion to survival rates. In the case of entrainment, the basic calculation is:

$$S_{j,1} = S_j^* \prod_{i=j+1}^{j_{\max}} S_i \qquad \text{(Equation 4)}$$

where:

$S_{j,1}$ = cumulative survival from stage *j* until age 1
S_i = survival fraction from stage *i* to stage *i* + 1
S^*_j = $2S_j e^{-\log(1+S_j)}$ = adjusted S_j
$j_{\max}$ = the stage immediately prior to age 1

Equation 4 defines $S_{j,1}$, which is the expected cumulative survival rate (as a fraction) from the stage at which entrainment occurs, *j*, through age 1. The components of Equation 4 represent survival rates during the different life stages between life stage *j*, when a fish is entrained, and age 1. Survival through the stage at which entrainment occurs, *j*, is treated as a special case because the amount of time spent in that stage before entrainment is unknown and therefore the known stage specific survival rate, S_j, does not apply because S_j describes the survival rate through the entire length of time that a fish is in stage *j*. Therefore, to find the expected survival rate from the day that a fish was entrained until the time that it would have passed into the subsequent stage, an adjustment to S_j is required. The adjusted rate S^*_j describes the effective survival rate for the group of fish entrained at stage *j*, considering the fact that the individual fish were entrained at various specific ages within stage *j*.

Age-1 equivalents are then calculated as:

$$AE1_{j,k} = L_{j,k}\, S_{j,1} \qquad \text{(Equation 5)}$$

where:

$AE1_{j,k}$ = the number of age-1 equivalents killed during life stage *j* in year *k*
$L_{j,k}$ = the number of individuals killed during life stage *j* in year *k*
$S_{j,1}$ = the cumulative survival rate for individuals passing from life stage *j* to age 1 (equation 4)

The total number of age-1 equivalents derived from losses at all stages in year *k* is then given by:

(Equation 6)

$$AE1_k = \sum_{j = j_{\min}}^{j_{\max}} AE1_{j,k}$$

where:

$AE1_k$ = the total number of age-1 equivalents derived from losses at all stages in year k

A5-4.2 Modeling Foregone Fishery Yield

Foregone fishery yield is a measure of the amount of fish or shellfish (in pounds) that is not harvested because the fish are lost to I&E. EPA estimated foregone yield using the Thompson-Bell equilibrium yield model (Ricker, 1975). The model provides a simple method for evaluating a cohort of fish that enters a fishery in terms of their fate as harvested or not-harvested individuals. EPA's application of the Thompson-Bell model assumes that I&E losses result in a reduction in the number of harvestable adults in years after the time that individual fish are killed by I&E and that future reductions in I&E will lead to future increases in fish harvest.

The Thompson-Bell model is based on the same general principles that are used to estimate the expected yield in any harvested fish population (Hilborn and Walters, 1992; Quinn and Deriso, 1999). The general procedure involves multiplying age-specific harvest rates by age-specific weights to calculate an age-specific expected yield (in pounds). The lifetime expected yield for a cohort of fish is then the sum of all age-specific expected yields, thus:

(Equation 7)

$$Y_k = \sum_j \sum_a L_{jk} S_{ja} W_a (F_a / Z_a)\left(1 - e^{-Z_a}\right)$$

where:

Y_k = foregone yield (pounds) due to I&E losses in year k
L_{jk} = losses of individual fish of stage j in the year k
S_{ja} = cumulative survival fraction from stage j to age a
W_a = average weight (pounds) of fish at age a
F_a = instantaneous annual fishing mortality rate for fish of age a
Z_a = instantaneous annual total mortality rate for fish of age a

The model assumes that:

- the yield from a cohort of fish is proportional to the number recruited,
- annual growth, natural mortality, and fishing mortality rates are known and constant, and
- natural mortality includes mortality due to I&E

The assumption that fishing mortality, F, remains constant despite possible reductions in I&E is central to the modeling approach used to estimate changes in fishery yield. This assumption implies that fishing activity and fishing regulations will adapt to increases in fish stock in a manner that leads to harvest increases in direct proportion to the magnitude of increases in harvestable stock.

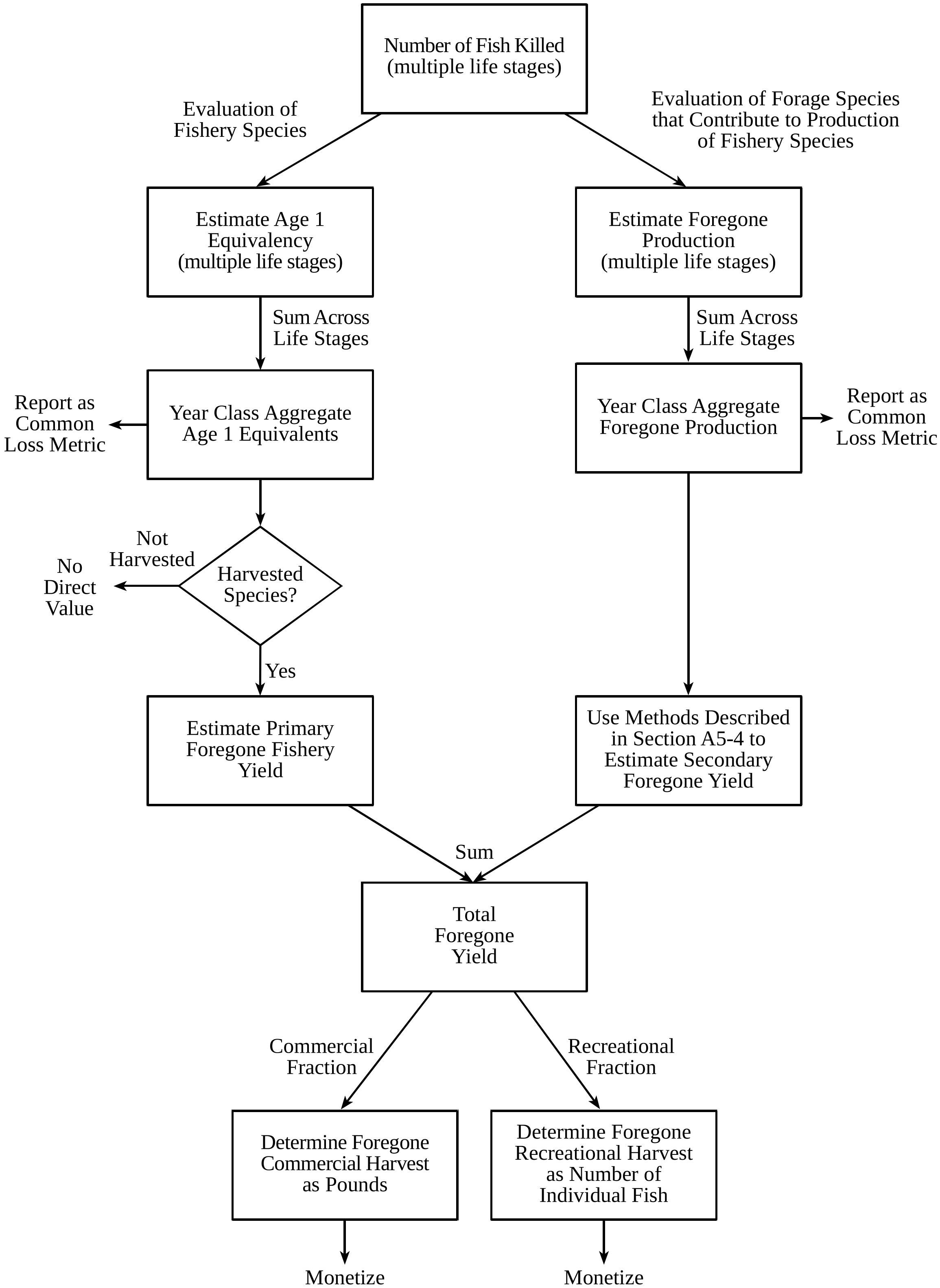
The assumption that M and F are constant is based on EPA's assumption that:

- I&E losses are a relatively minor source of mortality in comparison to the total effects of all other sources of natural mortality (e.g., predation); and
- the scale of changes in I&E loss rates being considered will not lead to dramatically large increases in the size of harvestable stocks.

EPA acknowledges that in some cases the importance of I&E as a source of mortality in a fishery might be large enough that it would be unlikely that natural and fishing mortality would remain constant, but such cases are not expected to be the norm.

As indicated in Figure A5-1, EPA partitioned its estimates of total foregone yield for each species into two classes, foregone recreational yield and foregone commercial yield, based on the relative proportions of recreational and commercial state-wide aggregate catch rates of that species in that region. Pounds of foregone yield to the recreational fishery were re-expressed as numbers of individual fish based on the expected weight of an individual harvestable fish. Chapter A9 describes the methods used to derive dollar values for foregone commercial and recreational yields for the regional benefits analyses.

Figure A5-1: General Approach Used to Evaluate I&E Losses as Foregone Fishery Yield



A5-4.3 Modeling Production Foregone

In addition to expressing I&E losses as lost age 1 equivalents (and subsequent lost yield, for harvested species), I&E losses were also expressed as foregone production. Foregone production is the expected total amount of future growth (expressed as pounds) of individuals that were impinged or entrained, had they not been impinged or entrained.

Production foregone is calculated by simultaneously considering the stage-specific growth increments and survival probabilities of individuals lost to I&E, where production includes the biomass accumulated by individuals alive at the end of a time interval as well as the biomass of those individuals that died before the end of the time interval. Thus, the production foregone for a specified stage, *i*, is calculated as:

$$P_i = \frac{G_i N_i W_i (e^{(G_i - Z_i)} - 1)}{G_i - Z_i} \quad \text{(Equation 8)}$$

where:

P_i = expected production (pounds) for an individual during stage *i*
G_i = the instantaneous growth rate for individuals of stage *i*
N_i = the number of individuals of stage *i* lost to I&E (expressed as equivalent losses at subsequent stages)
W_i = average weight (in pounds) for individuals of stage *i*
Z_i = the instantaneous total mortality rate for individuals of stage *i*

P_j, the production foregone for all fish lost at stage *j*, is calculated as:

$$P_j = \sum_{i=j}^{t_{max}} P_{ji} \quad \text{(Equation 9)}$$

where:

P_j = the production foregone for all fish lost at stage *j*
t_{max} = oldest stage considered

P_T, the total production foregone for fish lost at all stages *j*, is calculated as:

$$P_T = \sum_{j=t_{min}}^{t_{max}} P_j \quad \text{(Equation 10)}$$

where:

P_T = the total production foregone for fish lost at all stages *j*
t_{min} = youngest stage considered

A5-4.4 Evaluation of Forage Species Losses

Foregone production of forage species due to I&E losses may be considered a reduction in the aquatic food supply, and therefore a cause of reduced production of other species, including harvested species, at higher trophic levels. I&E losses of forage species have both immediate and future impacts because not only is existing biomass removed from the ecosystem, but also the biomass that would have been produced in the future is no longer available as food for predators (Rago, 1984; Summers, 1989). The Production Foregone Model accounts for these consequences of I&E losses by considering losses of both existing biomass and the biomass that would have been transferred to other trophic levels but for the removal of organisms by I&E (Rago, 1984; Dixon, 1999). Consideration of the future impacts of current losses is particularly important for fish, since there can be a substantial time between loss and replacement, depending on factors such as spawning frequency and growth rates (Rago, 1984).

To evaluate I&E losses of forage species (i.e., species that are not targets of recreational or commercial fisheries) EPA translated foregone production among forage species into foregone production among harvested species that are impinged and entrained using a trophic transfer ratio, and then translated foregone production among these harvested species to foregone yield. These estimates of the foregone yield of impinged and entrained harvested species were distinct from the primary foregone yield of these species and are termed "secondary yield". This procedure is illustrated in detail in Equation 11, Equation 12, and schematically in Figure A5-2.

The basic assumption behind EPA's approach to evaluating losses of forage species is that a decrease in the production of forage species can be related to a decrease in the production of impinged and entrained harvested (predator) species based on an estimate of trophic transfer efficiency. Thus, in general,

$$P_h = k\, P_f \qquad \text{(Equation 11)}$$

where:

P_h = foregone biomass production of a harvested species h (in pounds)
k = the trophic transfer efficiency
P_f = foregone biomass production of a forage species f (in pounds)

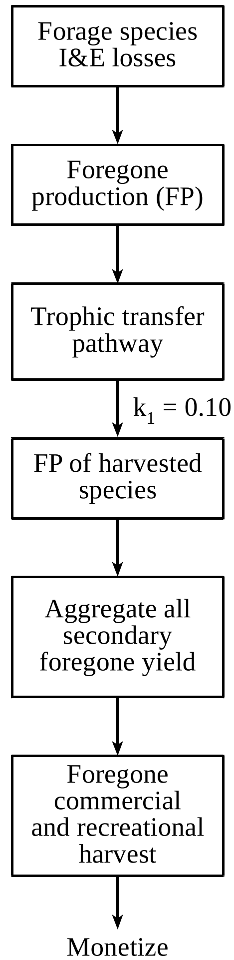
Equation 11 is applicable to trophic transfer on a species-to-species basis where one species is strictly prey and the other species is strictly a predator. For the section 316(b) regional studies, commercially or recreationally valuable fish were considered predators. The aggregate total secondary yield is estimated on a regional basis under the assumption that the trophic value of total foregone production among forage species is allocated equally among all harvested species that occur in the I&E losses, thus:

$$Y_{sec} = \sum_{\substack{h \in all \\ harvested \\ species}} \left(\frac{k}{H} \sum_{\substack{f \in all \\ forage \\ species}} P_f \right) \left(Y_h \big/ P_h \right) \qquad \text{(Equation 12)}$$

where:

Y_{sec} = total secondary yield (as a generic predator species)
H = number of harvested species among regional loss estimates
Y_h = primary estimate of foregone yield for harvested species h
P_h = estimate of foregone production for harvested species h

Figure A5-2: Trophic Transfer Model for Valuation of Foregone Biomass Production (FP) of Forage Species by Estimating Consequential Reductions in Commercial and Recreational Harvest



It is difficult to determine, on a community basis, an appropriate value of *k* that relates aggregate forage production and aggregate predator production, since the actual trophic pathways are complicated. For the purposes of the regional case studies, EPA used the value of $k = 0.10$ (Pauly and Christensen, 1995).

A5-5 Extrapolation of I&E Rates

I&E data are not available for all facilities in scope of the Phase II rule. Therefore, EPA examined I&E losses, and the economic benefits of reducing these losses, at the regional level. The estimated benefits were then aggregated across all regions to yield a national benefit estimate. Extrapolation was necessary because not all in scope facilities within a given region have conducted I&E studies.

To obtain regional impingement and entrainment estimates, EPA extrapolated losses observed at the 46 facilities evaluated (facilities with suitable records of impingement and entrainment rates) to other in-scope facilities within the same region. EPA defined seven regions for its regional analysis based on similarities among the affected aquatic species and characteristics of commercial and recreational fishing activities in the area. The extrapolation was done separately for each region (North Atlantic, Mid-Atlantic, South Atlantic, Gulf of Mexico, Northern California, Southern California, Great Lakes and Inland). These regions and the water body types within each region are described in the Introduction to this Regional Analysis Document. Maps showing the facilities in each region that are in scope of the Phase II rule are provided in the introductory chapter of each regional report (Parts B-H of this document).

Impingement and entrainment data were extrapolated on the basis of operational flow, in millions of gallons per day (MGD), where MGD is the average operational flow over the period 1996-1998 as reported by facilities in response to EPA's section 316(b) Detailed Questionnaire and Short Technical Questionnaire. Operational flow at each facility was rescaled using factors reflecting the relative effectiveness of currently in-place technologies for reducing impingement and entrainment. Thus,

$$F_{f,e} = G_f\,(1-T_{f,e}) \qquad \text{(Equation 13)}$$

where:

$F_{f,e}$ = effective relative flow rate for entrainment at facility *f*
G_f = mean operational flow at facility *f* (10^6 gallons/day)
$T_{f,e}$ = fractional effectiveness of entrainment-reducing technology at facility *f* ($0<T_{f,e}<1$)

$$F_{f,i} = G_f\,(1-T_{f,i}) \qquad \text{(Equation 14)}$$

where:

$F_{f,i}$ = effective relative flow rate for impingement at facility *f*
G_f = mean operational flow at facility *f* (10^6 gallons/day)
$T_{f,i}$ = fractional effectiveness of impingement-reducing technology at facility *f* ($0<T_{f,i}<1$)

$$S_{r,e} = \sum_{\substack{f\,\in \text{All facilities} \\ \text{in region r}}} F_{f,e} \Bigg/ \sum_{\substack{f\,\in \text{All model facilities} \\ \text{in region r}}} F_{f,e} \qquad \text{(Equation 15)}$$

where:

$F_{f,e}$ = effective relative flow rate for entrainment at facility *f*
$S_{r,e}$ = scaling factor to relate total entrainment losses among model facilities to regional total entrainment losses

$$S_{r,i} = \sum_{\substack{f\,\in \text{All facilities} \\ \text{in region r}}} F_{f,i} \Bigg/ \sum_{\substack{f\,\in \text{All model facilities} \\ \text{in region r}}} F_{f,i} \qquad \text{(Equation 16)}$$

where:

$F_{f,i}$ = effective relative flow rate for impingement at facility *f*
$S_{r,i}$ = scaling factor to relate total impingement losses among model facilities to regional total impingement losses

$$L_{r,e} = S_{r,e} \sum_{\substack{f \in \text{All model facilities} \\ \text{in region r}}} L_{f,e}$$ (Equation 17)

where:

$S_{r,e}$ = scaling factor to relate total entrainment losses among model facilities to regional total entrainment losses
$L_{r,e}$ = estimated annual total entrainment losses at region *r*
$L_{f,e}$ = estimated annual total entrainment losses at facility *f*

$$L_{r,i} = S_{r,i} \sum_{\substack{f \in \text{All model facilities} \\ \text{in region r}}} L_{f,i}$$ (Equation 18)

where:

$S_{r,i}$ = scaling factor to relate total impingement losses among model facilities to regional total impingement losses
$L_{r,i}$ = estimated annual total impingement losses at region *r*
$L_{f,i}$ = estimated annual total impingement losses at facility *f*

The values of the regional scaling factors $S_{r,e}$ ranged from 1.0 to 11.7, and $S_{r,i}$ ranged from 1.0 to 12.1 (Table A5-2). The unweighted average values of $S_{r,e}$ and $S_{r,i}$ were 4.42 and 5.56, respectively, indicating that loss estimates derived from empirical records at the model facilities comprise roughly 23% and 18% of the estimates of national total entrainment and impingement, respectively.

Table A5-2: Regional Scaling Factors $S_{r,e}$ and $S_{r,i}$ Used to Extrapolate Total Annual I&E Losses Among Model Facilities to Total Annual I&E Losses Among All In-Scope Facilities Within Each Region

Region	S_{re}	S_{ri}
Inland	11.74	9.69
Mid Atlantic	5.14	12.11
North Atlantic	3.21	5.15
Northern California	1.00	1.00
Southern California	1.20	1.26
Great Lakes	5.15	4.44
Gulf of Mexico	3.52	5.25

There may be substantial among-facility variation in the actual I&E losses per MGD that results from a variety of facility-specific features, such as location and type of intake structures, as well as from ecological features that affect the abundance or species composition of fish in the vicinity of each facility. The accuracy of the extrapolation procedure relies heavily on the assumption that I&E rates recorded at model facilities are representative of I&E rates at other facilities in the region. Although this assumption may be violated in some cases, limiting the extrapolation procedure to particular regions reduces the likelihood that the model facilities are unrepresentative.

EPA believes that this method of extrapolation makes best use of a limited amount of empirical data, and is the only currently feasible approach for developing an estimate of national I&E and the benefits of reducing I&E. While acknowledging that an extrapolation necessarily introduces uncertainty into I&E estimates, EPA has not identified information that suggests that application of the procedure causes a systematic bias in the regional loss estimates (see Chapter A6 for additional discussion of uncertainty and bias).

The assumption that I&E is proportional to flow is consistent with other predictive I&E studies. For example, a key assumption of the Spawning and Nursery Area of Consequence (SNAC) model (Polgar, 1979) is that entrainment is proportional to cooling water withdrawal rates. The SNAC model has been used as a screening tool for assessing potential I&E impacts at Chesapeake Bay plants. As a first approximation, percent entrainment has been predicted on the basis of the ratio of cooling water flow to source water flow (Goodyear, 1978). A study of power plants on the Great Lakes (Kelso and Melburn 1979) demonstrated an increasing relationship (on a log-log scale) between plant "size" (electric production in MWe) and impingement and entrainment. There is scatter in these relationships, not just because there is variation in the cooling water intake for different plants having similar electric production, but also because of the imprecision (sampling variability) inherent in the usual methods of estimating impingement and entrainment. These relationships are nonetheless strong. EPA’s 1976 “Development Document for the Best Technology Available for the Location, Design, Construction and Capacity of Cooling Water Intake Structures for Minimizing Adverse Environmental Impact” concluded that “reduction of cooling water intake volume (capacity) should, in most cases, reduce the number of organisms that are subject to entrainment in direct proportion to the fractional flow reduction.”