Chapter G5: HRC Valuation of I&E Losses at the Pilgrim Facility

EPA applied the habitat replacement cost (HRC) method, as described in Chapter A11 of Part A of this document, to value the average annual losses to impingement and entrainment (I&E) at the Pilgrim cooling water intake structure (CWIS) (Seabrook was not evaluated because of budget constraints). To summarize, the HRC method identifies the habitat restoration actions that are most effective at replacing the species that suffer I&E losses at a CWIS. Then, the HRC method determines the amount of each restoration action that is required to offset fully the I&E losses. Finally, the HRC method estimates the cost of implementing the restoration actions, and uses this cost as a proxy for the value of the I&E losses. Thus, the HRC valuation method is based on the estimated cost to replace the organisms lost because of I&E, where the replacement is achieved through improvement or replacement of the habitat upon which the lost organisms depend. The HRC method produces an estimated annualized total value of $9.2 million, which is the cost of replacing the impinged and entrained organisms through the restoration of submerged aquatic vegetation (SAV), restoration of tidal wetlands, construction of artificial reefs, and installation of fish passageways and monitoring to quantify the productivity of these habitats.

The HRC method is a supply-side approach for valuing I&E losses in contrast to the more typically used demand-side valuation approaches (e.g., commercial and recreational fishing impacts valuations discussed in Chapter A9 of Part A of this document). An advantage of the HRC method is that it can address, and value, losses for all species, including those lacking a recreational or commercial fishery (e.g., forage species). Further, the HRC method explicitly recognizes and captures the fundamental ecological relationships between those species with I&E losses at a facility and their surrounding environment, in contrast to traditional replacement cost methods such as fish stocking.

EPA used published data wherever possible to apply the HRC method to the I&E losses at the Pilgrim facility. If published data were lacking, EPA used unpublished data from knowledgeable resource experts. In some cases, EPA used (and documented) the best professional judgment of these experts to apply reasonable assumptions to their data. In these cases, EPA applied cost-reducing assumptions, but not beyond the range of values that experts were willing to support as reasonable. In other words, this HRC valuation seeks the cost of what knowledgeable resource experts consider to be the minimum amount of restoration necessary to offset I&E losses at the Pilgrim facility.

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Cost-reducing assumptions are identified throughout this chapter and were incorporated extensively. Most significantly, the HRC valuation estimates for the I&E losses at the Pilgrim facility implicitly assumes that the scale of restoration determined for species for which data were available are sufficient to fully offset the losses for species for which no data was identified. To the degree this assumption is inaccurate, the results incorporate a downward bias.

Sections G5-1 through G5-8 present the information, methods, assumptions, and conclusions that were used to complete the HRC valuation of the I&E losses at the Pilgrim facility following the eight steps described in Chapter A11 of Part A of this document. Section G5-8 also presents additional detail on the valuation of the I&E losses at the Pilgrim facility, providing separate annualized valuation estimates for the aquatic organisms lost to impingement and for those lost to entrainment.

G5-1 Step 1: Quantify I&E Losses

The Pilgrim facility has reported I&E losses of millions of aquatic organisms each year since it began using a once-through CWIS. EPA evaluated all species known to be impinged and entrained by the Pilgrim facility, including commercial, recreational, and forage fish species, based on information provided in facility I&E monitoring reports and detailed in Chapter G3.

Of the 63 species of fish with reported I&E losses at the Pilgrim facility, EPA incorporated the 34 species that had losses greater than 0.1 percent of the total impingement or total entrainment losses at the facility (the criterion for inclusion in the Equivalent Adult Model [EAM]) into the HRC analysis. The average annual age 1 equivalent losses from I&E at Pilgrim for these 34 species from 1974 to 1999 calculated by the EAM (see Chapter G3 for additional descriptions of source data and calculation of the age 1 equivalents) are presented in Table G5-1, in order of decreasing mean annual I&E losses (this information is also presented in Tables G3-6 and G3-10).

In addition, quantitative estimates of blue mussel losses were available for a number of years in Pilgrim's I&E monitoring reports. The losses for blue mussels were quantified as age 1 equivalents using the same EAM model. The I&E losses for blue mussels are also presented in Table G5-1.

Table G5-1: Mean Annual Age 1 Equivalent I&E Losses of Fishes at the Pilgrim Facility, 1974-1999

Species	Impingement	Entrainment	Total
Finfish			
Rock gunnel	77	4,862,795	4,862,872
American sand lance	27	4,116,258	4,116,285
Radiated shanny	54	1,644,402	1,644,456
Rainbow smelt	6,885	1,323,137	1,330,022
Cunner	411	993,500	993,911
Sculpin spp.	13	734,760	734,773
Fourbeard rockling	2	411,189	411,191
Winter flounder	1,144	209,571	210,715
Atlantic herring	8,836	20,243	29,079
Atlantic silverside	20,842	5,087	25,929
Windowpane	284	17,258	17,542
Atlantic menhaden	6,165	8,105	14,270
Atlantic mackerel	3	6,659	6,662
Alewife	4,343	0	4,343
Searobin	69	3,698	3,767
Atlantic cod	301	2,138	2,439
Red hake	229	1,545	1,774
Lumpfish	217	1,080	1,297
Tautog	201	875	1,076
Grubby	879	NA	879

Table G5-1: Mean Annual Age 1 Equivalent I&E Losses of Fishes at the Pilgrim Facility, 1974-1999 (cont.)			
Species	**Impingement**	**Entrainment**	**Total**
Blueback herring	703	NA	703
Pollock	33	492	525
Butterfish	399	NA	399
American plaice	0	221	221
Northern pipefish	118	NA	118
Threespine stickleback	118	NA	118
Scup	114	NA	114
Striped killifish	90	NA	90
Little skate	78	NA	78
White perch	73	NA	73
Bay anchovy	18	NA	18
Striped bass	9	NA	9
Bluefish	2	NA	2
Hogchoker	2	NA	2
Total age 1 eq. finfish losses	52,739	14,363,013	14,415,752
Shellfish			
Blue mussel	15	160,000,000,000	160,000,000,000[a]
Total age 1 eq. shellfish losses	15	160,000,000,000	160,000,000,000[a]

[a] Rounded to nearest billion.

G5-2 Step 2: Identify Habitat Requirements

Determining the best course of action for restoring habitat to offset losses of species to I&E requires understanding the specific habitat requirements for each species. Habitat requirements for fish may include physical habitat needs such as substrate types and geographic locations as well as water quality needs and food sources. Chapter G3, Section G3-2, provides a detailed summary of the habitat components needed for the critical lifestages of several of the species from among those with high average annual I&E losses at the Pilgrim facility.

G5-3 Step 3: Identify Potential Habitat Restoration Alternatives to Offset I&E Losses

Local experts identified six types of projects that could be used near the Pilgrim facility to restore the same species of fish and aquatic organisms lost to I&E at the Pilgrim facility:

- restore submerged aquatic vegetation (SAV)
- restore tidal wetlands
- create artificial reefs
- improve anadromous fish passage
- improve water quality beyond current regulatory requirements
- reduce fishing pressures beyond current regulatory requirements.

Of the project categories listed above, the restoration of SAV and tidal wetlands, the creation of artificial reefs and the improvement of anadromous fish passages provides benefits to the aquatic community that can be quantified in this HRC valuation and are described below.

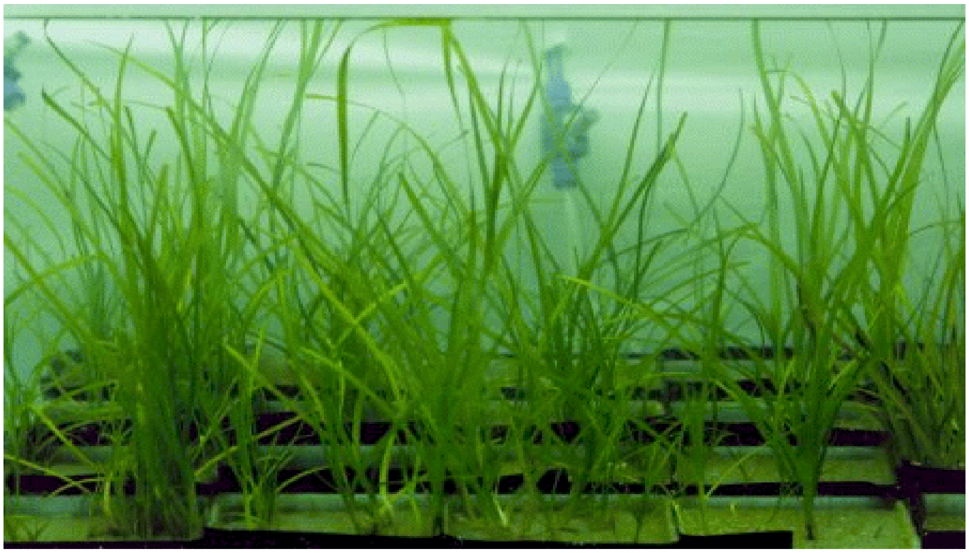
Restore submerged aquatic vegetation

Submerged aquatic vegetation provides vital habitat for a number of aquatic organisms. Eelgrass is the dominant species of SAV along the coasts of New England. It is an underwater flowering plant that is found in brackish and near-shore marine waters (Figure G5-1). Eelgrass can form large meadows or small separate beds that range in size from many acres to just 1 m across (Save The Bay, 2001).

SAV restoration involves transplanting eelgrass shoots and/or seeds into areas that can support their growth. Site selection is based on historical distribution, wave action, light availability, sediment type, and nutrient loading. Improving water quality and clarity, reducing nutrient levels, and restricting dredging may all be necessary to promote sustainable eelgrass beds. Protecting existing SAV beds is a priority in many communities (Save The Bay, 2001).

SAV provides several ecological services to the environment. For example, eelgrass has a high rate of leaf growth and provides support for many aquatic organisms as shelter, spawning, and nursery habitat. SAV is also a food source for herbivorous organisms. The roots of SAV also provide stability to the bottom sediments, thus decreasing erosion and resuspension of sediments into the water column (Thayer et al., 1997). Dense SAV provides shelter for small and juvenile fishes and invertebrates from predators. Small prey can hide deep within the SAV canopy, and some prey species use the SAV as camouflage (Thayer et al., 1997). Species impinged and entrained at Pilgrim that use SAV beds during early life stages include Atlantic menhaden, striped bass, tautog, bluefish, and rainbow smelt (Laney, 1997).

Figure G5-1: Laboratory culture of eelgrass (Zostera marina)



Source: Boschker, 2001.

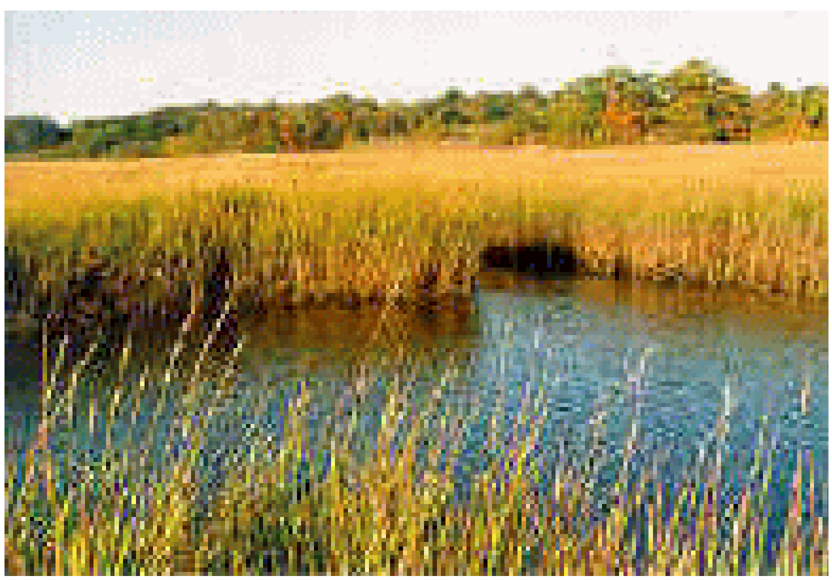
Restore tidal wetlands

Tidal wetlands (Figure G5-2) are among the most productive ecosystems in the world (Mitsch and Gosselink, 1993; Broome and Craft, 2000). They provide valuable habitat for many species of invertebrates and forage fish that serve as food for other species in and near the wetland. Tidal wetlands also provide spawning and nursery habitat for many other fish species, including the Atlantic silverside, striped killifish, threespine stickleback, and mummichog. Other migratory species that use tidal wetlands during their lives include the winter flounder, striped bass, Atlantic herring, and white perch (Dionne et al., 1999). Fish species that have been reported in restored salt ponds and tidal creeks include Atlantic menhaden, blueback herring, Atlantic silverside, striped killifish, and mummichog (Roman et al., submitted 2000 to *Restoration Ecology*). Restoring tidal flow to areas where such flows have been restricted also reduces the presence of *Phragmites australis*, the invasive marsh grass that has choked out native flora and fauna in coastal areas across the New England seaboard (Fell et al., 2000).

Figure G5-2: Tidal creek near Little Harbor, Cohasset, Massachusetts (*Source*: MAPC, 2001)

Tidal wetlands restoration typically involves returning tidal flow to marshes or ponds that have restricted natural tidewater flow because of roads, backfilling, dikes, or other barriers. Eliminating these barriers can restore salt marshes (Figure G5-3), salt ponds, and tidal creeks that provide essential habitat for many species of aquatic organisms. For example, where undersized culverts restrict tidal flow, installing correctly sized and positioned culverts can restore tidal range and proper salinity. In other situations, such as where low-lying property adjacent to salt marsh has been developed, restoring full tidal flow may not be possible because of flooding concerns (MAPC, 2001). Salt marshes can also be created by inundating areas in which no marsh habitat previously existed (e.g., tidal wetland creation). However, a study by Dionne et al. (1999) showed that while both created and restored tidal wetlands provide habitat for a number of fish, restored tidal wetlands provide much larger and more productive areas of habitat per unit cost than created tidal wetlands.

Figure G5-3: Salt marsh near Narragansett Bay, Rhode Island (*Source*: Save the Bay, 2001)



Create artificial reefs

Several species of fish found near the Pilgrim facility use rocky or reef-like habitats with interstices that provide refuge from predators. These habitats can be created artificially with cobbles, concrete, and other suitable materials. Species impinged and entrained at Pilgrim that commonly use reef structures for refuge include tautog, cunner, and blue mussels (Foster et al., 1994; Castro et al., in press). Both cunner and tautog become torpid at night and require places to hide from their prey.

Improve anadromous fish passageways

Anadromous fish spend most of their lives in brackish or saltwater but migrate into freshwater rivers and streams to spawn. Dams on many of the rivers and streams in this region where anadromous fish historically spawned make these waterways inaccessible to migrating fish. Anadromous fish impinged and entrained at Pilgrim that would benefit from improved access to upstream spawning habitat include rainbow smelt, alewife, and white perch.

Improving anadromous fish passage involves many important steps. Dams and barriers connecting estuaries with upstream spawning habitat can be removed or fitted with fish ladders (Figure G5-4). Removing a dam is often preferable because some species such as rainbow smelt use fish ladders ineffectively. However, dam removal may not be possible in highly developed areas needing flood control. In addition, restoring stream habitats such as forested riverbank wetlands and improving water quality may also be necessary to restore upstream spawning habitats for anadromous fish (Save The Bay, 2001).

Figure G5-4: Example of a fish ladder at a hydroelectric dam

Source: Pollock, 2001.

G5-4 Step 4: Consolidate, Categorize, and Prioritize Identified Habitat Restoration Alternatives

EPA categorized and prioritized habitat restoration alternatives to identify the type of restoration program that was best suited for each of the major species that are impinged or entrained as a result of cooling water intakes. This was done in collaboration with local experts from several federal, state, and local organizations at a meeting on September 12, 2001 (Table G5-2), and through follow-up discussions that were held with numerous additional organizations (Table G5-3).

Attendees discussed habitat needs and restoration options for each species with significant I&E losses at the facility. They then ranked these restoration options for each species by determining what single option would most benefit that species. The alternatives chosen for each species are shown in Table G5-4.

Table G5-2: Attendees at the Meeting on Habitat Prioritization for Species Impinged and Entrained at Pilgrim September 12, 2001, in Lakeville, Massachusetts

Attendee	Organization
Bob Green	Massachusetts DEP
Robert Lawton	Massachusetts Division of Marine Fisheries
George Zoto	Massachusetts Watershed Initiative - South Coastal Watersheds
Kathi Rodrigues	National Marine Fisheries Service - Restoration Center
David Webster	U.S. EPA Region I
Sharon Zaya	U.S. EPA Region I
Nick Prodany	U.S. EPA Region I
John Nagle	U.S. EPA Region I

Table G5-3: Local Agencies and Organizations Contacted for Information Used in this HRC Analysis

Organization
Applied Sciences Associates
Atlantic States Marine Fisheries Council
Connecticut College
Duxbury Conservation Agency
Fall River Conservation Commission
Jones River Watershed Association
Massachusetts Office of Coastal Zone Management
Massachusetts Department of Environmental Protection
Massachusetts Department of Fisheries, Wildlife, and Law Enforcement — Division of Marine Fisheries
Massachusetts Institute of Technology Sea Grant Program: Center for Coastal Resources
Massachusetts Watershed Initiative
Metropolitan Area Planning Commission
Narragansett Estuarine Research Reserve
National Estuary Program — Massachusetts Bays program
National Estuary Program — Narragansett Bay Estuary Program
New Jersey Department of Environmental Protection
New Jersey Marine Sciences Consortium
NOAA — National Marine Fisheries Service
NOAA — National Marine Fisheries Service — Restoration Center (Gloucester, MA)
NOAA — National Marine Fisheries Service — Restoration Center (Providence, RI)
NOAA — National Marine Fisheries Service (NC)

Table G5-3: Local Agencies and Organizations Contacted for Information Used in this HRC Analysis (cont.)

Organization
Rhode Island Coastal Resource Management Council
Rhode Island Department of Environmental Management
Rhode Island Department of Environmental Management — Dept. of Planning and Development, Land Acquisition Program
Rhode Island Department of Environmental Management — Division of Fish and Wildlife
Rhode Island Department of Environmental Management — Marine Fisheries Section
Roger Williams University
Rutgers University
Save The Bay (RI)
Somerset Conservation Commission
University of California — Santa Cruz: Department of Ecology and Evolutionary Biology
University of New Hampshire
University of Rhode Island
USEPA — Region 1
USEPA Environmental Effects Research Laboratory — Atlantic Ecology Division/ORD
US Fish and Wildlife Service
USGS
Wetlands Restoration Program, (Mass Exec. Office of Env. Affairs)
Woods Hole Oceanographic Institution

Table G5-4: Preferred Restoration Alternatives Identified by Experts for Species Impinged and Entrained at Pilgrim

Species (age 1 eq. losses per year)	Selected Restoration Alternative
Atlantic cod (2,439)	SAV restoration
Pollock (525)	SAV restoration
Northern pipefish (118)	SAV restoration
Threespine stickleback (118)	SAV restoration, tidal wetland restoration
American sand lance (4,116,285)	Tidal wetlands restoration
Winter flounder (210,715)	Tidal wetlands restoration
Atlantic silverside (25,929)	Tidal wetlands restoration
Windowpane[a] (17,542)	Tidal wetlands restoration (improve habitat for prey)
Grubby (879)	Tidal wetlands restoration
Striped killifish (90)	Tidal wetlands restoration
Striped bass (9)	Tidal wetlands restoration (improve habitat for prey)
Bluefish (2)	Tidal wetlands restoration (improve habitat for prey)
Rock gunnel (4,862,872)	Artificial reef creation
Radiated shanny (1,644,456)	Artificial reef creation
Cunner (993,911)	Artificial reef creation, SAV restoration
Sculpin spp. (734,773)	Artificial reef creation, SAV restoration (improve habitat for prey)
Tautog (1,076)	Artificial reef creation, SAV restoration
Rainbow smelt (1,330,022)	Anadromous fish passage (remove dams)
Alewife (4,343)	Anadromous fish passage
Blueback herring (703)	Anadromous fish passage
White perch (73)	Anadromous fish passage

Table G5-4: Preferred Restoration Alternatives Identified by Experts for Species Impinged and Entrained at Pilgrim (cont.)

Species (age 1 eq. losses per year)	Selected Restoration Alternative
Blue mussels (160,000,000,000)	No habitat restoration/replacement alternative was identified.
Fourbeard rockling (411,191)	
Atlantic herring (29,079)	
Searobin (3,767)	
Red hake (1,774)	
Lumpfish (1,297)	
American plaice (221)	
Scup (114)	
Little skate (78)	
Hogchoker (2)	
Atlantic menhaden (14,270)	No habitat restoration/replacement alternative was identified.
Atlantic mackerel (6,662)	
Butterfish (399)	
Bay anchovy (18)	

[a] Improved water quality later became the chosen restoration alternative for windowpane because they inhabit depths greater than accessible to tidal wetland restoration. However, no specific water quality projects were identified.

G5-5 Step 5: Quantify the Expected Increases in Species Production for the Prioritized Habitat Restoration Alternatives

In Step 5, EPA estimated the expected increases in fish production attributable to implementing the preferred restoration alternative for each species. These estimates were adjusted to express production as increases in age 1 fish. This simplified the scaling of the preferred restoration alternatives (see Section G5-6) because the I&E losses were also expressed as age 1 equivalents.

Unfortunately, available quantitative data is not sufficient to estimate reliably the increase in fish production that is expected to result from the habitat restoration actions listed in Table G5-4. There is also limited data available on the production of these species in natural habitats that could be used to estimate production in restored habitats. Therefore, in this analysis EPA relied on quantitative information on fish species abundance in the habitats to be restored as a proxy for the increase in production expected through habitat restoration. The relationship between the measured abundance of a species in a given habitat and the increase in that species' production that would result from restoring additional habitat is complex and unique for each species. In some cases the use of abundance data may underestimate the true production that would be gained through habitat restoration, and in other cases it may overestimate the true production. Nevertheless, this assumption was necessary given the limited amount of quantitative data on fish species habitat production that is currently available.

G5-5.1 Estimates of Increased Age 1 Fish Production from SAV Restoration

SAV provides forage and refuge services for many fish species, increases sediment stability, and dampens the energy of waves and currents affecting nearby shorelines (Fonseca, 1992). SAV restoration is most effective where water quality is adequate and SAV coverage once existed. Table G5-5 presents the fish species impinged or entrained at Pilgrim that would benefit most from SAV restoration, along with annual average I&E losses 1974-1999, arranged by number of fish lost.

Table G5-5: Fish Species Impinged or Entrained at Pilgrim that Would Benefit Most from SAV Restoration

Species	Annual Average I&E Loss of Age 1 Equivalents (1974-1999)	Percentage of Total I&E Losses for All Fish Species
Atlantic cod	2,439	0.02%
Pollock	525	0.00%
Northern pipefish	118	0.00%
Threespine stickleback	118	0.00%
Total	3,200	0.02%

G5-5.1.1 Species abundance estimates in SAV habitats

No studies were available that provided direct estimates of increased fish production following SAV restoration for the species impinged or entrained at Pilgrim that would benefit most from SAV restoration. Therefore, EPA used abundance estimates to estimate increases in production following restoration. Abundance estimates are often the best available estimates of local habitat productivity, especially for early life stages with limited mobility. The sampling efforts that provide abundance estimates in SAV habitat and that were selected for this HRC valuation are described below.

Species abundance in Buzzards Bay SAV

Wyda et al. (in press) provide abundance estimates as fish per 100 m^2 of SAV for species caught in otter trawls in July and August 1996 at 24 sites within 13 Buzzards Bay estuaries, near Nantucket, Massachusetts, and at 28 sites within 6 Chesapeake Bay estuaries. These locations were selected based on information that eelgrass was present or had existed at the location.

The sampling at each location consisted of six 2-minute sampling runs using a 4.8 m semi-balloon otter trawl with a 3 mm mesh cod end liner that was towed at 5-6 km/hour. Late summer sampling was selected because eelgrass abundance is greatest then, and previous research had shown that late-summer fish assemblages are stable.

Forty-three fish species were caught in Buzzards Bay and 60 in Chesapeake Bay. Abundance estimates per 100 m^2 of SAV were reported for all fish species, and abundance estimates for specific SAV density categories were reported for species caught in more than 10 percent of the total number of trawls (15 species). EPA used only these SAV density-based results from the Buzzards Bay sampling for this HRC valuation because of its proximity to the facility. These SAV density-based results are presented in Table G5-6 for species impinged and entrained at Pilgrim and identified as benefitting most from SAV restoration.

Table G5-6: Average Abundance in Buzzards Bay SAV (eelgrass) Habitats for Fish Species Impinged or Entrained at Pilgrim that Would Benefit Most from SAV Restoration

Common Name	Species Abundance (# fish per 100 m^2)[a]	
	Low Density SAV Habitats	High Density SAV Habitats
Atlantic cod[b]	no obs.	no obs.
Pollock[b]	no obs.	no obs.
Northern pipefish	0.19	0.99
Threespine stickleback	0.22	0.13

[a] High density habitats are eelgrass areas with shoot densities > 100 per m^2 and shoot biomass (wet) > 100 g/m^2. Low density habitats do not meet these criteria.
[b] Atlantic cod and pollock were not caught in any Buzzards Bay trawls.
Source: Wyda et al. (in press).

Species abundance in Rhode Island coastal salt pond SAV

Hughes et al. (2000) conducted trawl samples in the SAV habitats of four Rhode Island coastal estuarine salt ponds and in four Connecticut estuaries during July 1999. As in Wyda et al. (in press), the sampling at each location involved six 2-minute sampling runs using a 4.8 m semi-balloon otter trawl with a 3 mm mesh cod end liner towed at 5-6 km/hour.

The report does not provide abundance estimates by species. However, a principal investigator provided abundance estimates expressed as the number of fish per 100 m^2 of SAV for the locations sampled in Rhode Island (Point Judith Pond, Ninigret Pond, Green Hill Pond, and Quonochontaug Pond; personal communication, J. Hughes, NOAA Marine Biological Laboratory, 2001). Average abundance estimates per 100 m^2 of SAV were calculated for each species and allocated to the same SAV habitat categories that were designated in Wyda et al. (in press) using shoot density and wet weight of shoots from Hughes et al. (2000). The sampling results for species impinged and entrained at Pilgrim and identified as benefitting most from SAV restoration are presented in Table G5-7.

Table G5-7: Average Abundance from Rhode Island SAV Sites for Pilgrim Species that Would Benefit Most from SAV Restoration

Species	Species Abundance (# fish per 100 m^2 of SAV habitat)[a]	
	Low Density SAV Habitats	High Density SAV Habitats
Atlantic cod	no obs.	no obs.
Pollock	no obs.	no obs.
Northern pipefish	0.23	3.03
Threespine stickleback	no obs.	19.67

[a] High density habitats are defined as areas with eelgrass shoot densities > 100 per m^2 and shoot biomass (wet) > 100 g/m^2. Low density habitats do not meet these criteria.
Source: personal communication, J. Hughes, NOAA, Marine Biological Laboratory, 2001.

Species abundance in Nauset Marsh (Massachusetts) estuarine complex SAV

Heck et al. (1989) provide capture totals for day and night trawl samples taken between August 1985 and October 1986 in the Nauset Marsh Estuarine Complex in Orleans/Eastham, Massachusetts, including two eelgrass beds: Fort Hill and Nauset Harbor. As in the other SAV sampling efforts, an otter trawl was used for the sampling, but with slightly larger mesh size openings in the cod end liner (6.3 mm versus 3.0 mm) than in Hughes et al. (2000) or Wyda et al. (in press).

With the reported information on the average speed, duration, and number of trawls used in each sampling period and an estimate of the width of the SAV habitat covered by the trawl from one of the study authors (personal communication, M. Fahay, NOAA, 2001), EPA calculated abundance estimates per 100 m^2 of SAV habitat.

Heck et al. (1989) also report that the dry weight of the SAV shoots is over 180 g/m^2 at both the Fort Hill and Nauset Harbor eelgrass habitat sites. Therefore, these locations would fall into the high density SAV habitat category used in Wyda et al. (in press) and Hughes et al. (2000) because the dry weight exceeds the wet weight criterion of 100 g/m^2 used in those studies.

Finally, Heck et al. (1989) provide separate monthly capture results from their trawls. The maximum monthly capture results for each species was used for the abundance estimates from this sampling. Because these maximum values generally occur in the late summer months, sampling time is consistent with the results from Wyda et al. (in press) and Hughes et al. (2000).

The species abundance values estimated from the sampling of the Fort Hill and Nauset Harbor SAV habitats are presented in Table G5-8.

Table G5-8: Average Abundance in Nauset Marsh Estuarine Complex SAV for Fish Species Impinged or Entrained at Pilgrim that Would Benefit Most from SAV Restoration

Species	Species Abundance (# fish per 100 m^2)[a]	
	Fort Hill — High Density SAV	Nauset Harbor — High Density SAV
Atlantic cod	no obs.	no obs.
Pollock	no obs.	no obs.
Northern pipefish	0.68	6.11
Threespine stickleback	5.92	47.08

[a] High density habitats are defined as areas with eelgrass shoot densities > 100 per m^2 and shoot biomass (wet) > 100 g/m^2.
Source: Heck et al., 1989.

G5-5.1.2 Adjusting SAV sampling results to estimate annual average increase in production of age 1 fish

EPA adjusted sampling-based abundance estimates to account for:

- sampling efficiency
- capture of life stages other than age 1
- differences in the measured abundances in natural SAV habitat versus expected productivity in restored SAV habitat.

The basis and magnitude of the adjustments are discussed in the following sections.

Adjusting for sampling efficiency

Fish sampling techniques are unlikely to capture or record all of the fish present in a sampled area because some fish avoid the sampling gear and some are captured but not collected and counted. The sampling efficiency for otter trawls is approximately 40 percent to 60 percent (personal communication, J. Hughes, NOAA Marine Biological Laboratory, 2001). EPA assumed a cost reducing sampling efficiency of 40 percent for this HRC analysis, and multiplied the SAV sampling abundance estimates by 2.5 (i.e., 1.0 divided by 40 percent). This assumption increases SAV productivity estimates and lowers SAV restoration cost estimates.

Adjusting sample abundance estimates to age 1 life stages

All sampled life stages were converted to age 1 equivalents for comparison to I&E losses, which were expressed as age 1 equivalents. The average life stage of the fish caught in Buzzards Bay (Wyda et al., in press) and the Rhode Island coastal salt pond (Hughes et al., 2000) was juveniles (i.e., life stage younger than age 1) (personal communication, J. Hughes, NOAA Marine Biological Laboratory, 2001). Since the same sampling technique and gear was used in Heck et al. (1989), EPA assumed juveniles to be the average life stage captured in this study as well.

The abundance estimates from the studies were multiplied by the survival rates from juveniles to age 1 for each species to provide an age 1 equivalent abundance. The juvenile to age 1 survival rate adjustment factors, calculated using the results of the EAM, are presented in Table G5-9.

As noted in the table, there are no juvenile to age 1 survival rate estimates used in the EAM for three of the species. However, survival rate estimates are available for these species from larval stage (the stage just prior to juvenile) to age 1. In these cases, EPA estimated the juvenile to age 1 survival rate by averaging the survival rate for larvae to age 1 with 1.0 (because 1.0 is necessarily the age 1 to age 1 survival rate). This procedure produces juvenile to age 1 survival rates that are approximately 0.5, which is near the maximum juvenile to age 1 survival rates used in the EAM for other species. Therefore, this assumption may lead to an overestimation of the juvenile to age 1 survival rate, and therefore to an overestimation of the age 1 fish produced by SAV restoration (and an underestimation of the amount of restoration required). Nevertheless, EPA used the adjustment factors shown in Table G5-9 to convert densities of juveniles in SAV habitat to densities of age 1 individuals, as a cost minimizing assumption.

Table G5-9: Life Stage Adjustment Factors for Species Present at Pilgrim — SAV Restoration

Species	Oldest Life Stage before Age 1 in the EAM	Estimated Survival Rate to Age 1	Life Stage Captured in SAV Sampling Efforts	Estimated Survival Rate for Juveniles to Age 1[a]
Atlantic cod	larvae	0.0023	juvenile	0.5012
Pollock	juvenile	0.0019	juvenile	0.0019
Northern pipefish	larvae	0.0703	juvenile	0.5352
Threespine stickleback	larvae	0.0567	juvenile	0.5284

[a] When the EAM included information only for larvae (younger than juvenile) to age 1, the juvenile to age 1 survival rate was assumed to be the average of larvae to age 1, and age 1 to age 1 (1.0).

Adjusting sampled abundance for differences between restored and undisturbed habitats

No reviewed studies suggested that restored SAV habitat would produce fish at a level different from undisturbed SAV habitat. Similarly, while service flows from a restored habitat site generally increase over time to a steady state level, limited anecdotal evidence suggests some restored SAV habitats may begin recruiting and producing fish very quickly (personal communication, A. Lipsky, Save the Bay, 2001). As a result of this limited evidence, and as a cost-reducing assumption, EPA made no adjustment for differences between restored and undisturbed SAV habitats to account for the final levels of fish production or potential lags in realizing these levels following restoration of SAV habitat.

G5-5.1.3 Final estimates of annual average age 1 fish production from SAV restoration

EPA calculated age 1 fish production expected from habitats where SAV is restored by multiplying the abundance estimates from Wyda et al. (in press), Hughes et al. (2000), and Heck et al. (1989) by the adjustment factors presented in the previous subsection. These results were then averaged, by species, across sampling locations to calculate the final production value incorporated in the scaling of the SAV restoration alternative.

Table G5-10 presents the final estimates of the increase in age 1 production for two of the four Pilgrim species that benefit most from SAV restoration (Atlantic cod and pollock were not sampled in any of the studies providing abundance estimates).

Table G5-10: Final Estimates of the Increase in Production of Age 1 Fish for Fish Species Impinged or Entrained at Pilgrim that Would Benefit Most from SAV Restoration

Species	Source of Initial Species Abundance Estimate	Species Abundance Estimate per 100 m^2 of SAV	Sampling Efficiency Adjustment Factor	Life Stage Adjustment Factor	Restored Habitat Service Flow Adjustment Factor	Expected Increase in Production of Age 1 Fish per 100 m^2 of Restored SAV
Northern pipefish	Heck et al. (1989) — Fort Hill	0.68	2.5	0.5352	1.0	0.91
	Heck et al. (1989) — Nauset Harbor	6.11	2.5	0.5352	1.0	8.17
	Hughes et al. (2000) — RI coastal ponds (low SAV)	0.23	2.5	0.5352	1.0	0.31
	Hughes et al. (2000) — RI coastal ponds (high SAV)	3.03	2.5	0.5352	1.0	4.06
	Wyda et al. (in press) — Buzzards Bay (low SAV)	0.19	2.5	0.5352	1.0	0.25
	Wyda et al. (in press) — Buzzards Bay (high SAV)	0.99	2.5	0.5352	1.0	1.32
	Species average					**2.50**
Threespine stickleback	Heck et al. (1989) — Fort Hill	5.92	2.5	0.5284	1.0	7.82
	Heck et al. (1989) — Nauset Harbor	47.08	2.5	0.5284	1.0	62.19
	Hughes et al. (2000) — RI coastal ponds (high SAV)	19.67	2.5	0.5284	1.0	25.98
	Wyda et al. (in press) — Buzzards Bay (low SAV)	0.22	2.5	0.5284	1.0	0.29
	Wyda et al. (in press) — Buzzards Bay (high SAV)	0.13	2.5	0.5284	1.0	0.17
	Species average					**19.29**
Atlantic cod	Unknown					
Pollock	Unknown					

G5-5.2 Estimates of Increased Age 1 Fish Production from Tidal Wetland Restoration

Tidal wetlands provide a diversity of habitats such as open water, subtidal pools, ponds, intertidal waterways, and tidally flooded meadows of salt tolerant grass species such as *Spartina alterniflora* and *S. patens*. These habitats provide forage, spawning, nursery, and refuge for a large number of fish species. Table G5-11 identifies the I&E losses for fish species at Pilgrim that would benefit most from tidal wetland restoration, along with average I&E losses for 1974-1999, arranged by number of fish lost.

Table G5-11: Fish Species Impinged or Entrained at Pilgrim that Would Benefit Most from Tidal Wetland Restoration

Species	Annual Average I&E Loss of Age 1 Equivalents (1974-1999)	Percentage of Total I&E Losses across all Fish Species
American sand lance	4,116,285	28.55%
Winter flounder	210,715	1.46%
Atlantic silverside	25,929	0.18%
Grubby	879	0.01%
Striped killifish	90	0.00%
Striped bass	9	0.00%
Bluefish	2	0.00%
Total	4,353,909	30.20%

Restricted tidal flows increase the dominance of *Phragmites australis* by reducing tidal flushing and lowering salinity levels (Buzzards Bay Project National Estuary Program, 2001a). *Phragmites* dominance restricts fish access to and movement through the water, decreasing overall productivity of the habitat. Therefore, for the purpose of this HRC valuation, tidal wetland restoration focuses on returning natural tidal flows to currently restricted areas. Examples of actions that can restore tidal flows to currently restricted tidal wetlands include the following:

- breaching dikes created to support salt hay farming or to control mosquitos
- installing properly sized culverts in areas currently lacking tidal exchange
- removing tide gates on existing culverts
- excavating dredge spoil covering former tidal wetlands.

EPA could not find any studies that quantified increased production following implementation of these types of restoration actions for tidal wetlands. Therefore, EPA used fish abundance estimates from studies of tidal wetlands to estimate the fish increase in fish production that can be gained through restoration. The following subsections present the sampling data and subsequent adjustments made to calculate the expected increased in age 1 production of fish species.

G5-5.2.1 Fish species abundance estimates in tidal wetland habitats

EPA used results from tidal wetland sampling efforts in Rhode Island to calculate the potential increased fish production from restored tidal wetland habitat. Available sampling results from Connecticut (Warren et al., 2001) and New Hampshire and Maine coasts (Dionne et al., 1999) were not used. The Connecticut results were omitted because regulatory time constraints prevented the conversion of capture results into abundance estimates per unit of tidal wetland area. The New Hampshire and Maine results were omitted because the study locations were too distant from the Pilgrim facility and are located north of the critical ecological divide of Cape Cod-Massachusetts Bay, which affects species mix and abundance.

Species abundance at Sachuest Point tidal wetland, Middletown, Rhode Island

Roman et al. (submitted 2000 to *Restoration Ecology*) sampled the fish populations in a 6.3 hectare (ha) tidal wetland at Sachuest Point in Middletown, Rhode Island. The sampling was conducted during August, September, and October of 1997, 1998, and 1999 using a 1 m^2 throw trap in the creeks and pools of each area during low tide after the wetland surface had drained. Additional sampling was conducted monthly from June through October in 1998 and 1999 using 6 m^2 bottomless lift nets to sample the flooded wetland surface. The report presents the results of this sampling as abundance estimates of each fish species per square meter (Table G5-12).

Roman et al. also sampled a smaller portion of the wetland where tidal flows had recently been restored. However, EPA did not use these results because the sampling was most likely conducted before the system reached full productivity.

Table G5-12: Abundance Estimates from the Unrestricted Tidal Wetlands at Sachuest for Fish Species Impinged or Entrained at Pilgrim that Would Benefit Most from Tidal Wetland Restoration

Species	Sampling Technique	Fish Density Estimates in Unrestricted Tidal Wetlands (fish per m^2)		
		1997	1998	1999
American sand lance	throw trap	no obs.	no obs.	no obs.
	lift net	no sampling	no obs.	no obs.
Winter flounder	throw trap	no obs.	no obs.	no obs.
	lift net	no sampling	no obs.	no obs.
Atlantic silverside	throw trap	1.23	0.20	0.07
	lift net	no sampling	no obs.	no obs.
Grubby	throw trap	no obs.	no obs.	no obs.
	lift net	no sampling	no obs.	no obs.
Striped killifish	throw trap	0.70	0.17	0.55
	lift net	no sampling	0.01	0.01
Striped bass	throw trap	no obs.	no obs.	no obs.
	lift net	no sampling	no obs.	no obs.
Bluefish	throw trap	no obs.	no obs.	no obs.
	lift net	no sampling	no obs.	no obs.

Source: Roman et al. (submitted 2000 to *Restoration Ecology*).

Galilee Marsh, Narragansett Rhode, Island

Raposa (in press) sampled the fish populations in the Galilee tidal wetland monthly from June through September of 1997, 1998, and 1999 using 1 m^2 throw trap in the creeks and pools in the tidal wetland parcels during low tide after the wetland surface had drained. Raposa presents the sampling results as fish species abundance expressed as number of fish per square meter. As with the results from Roman et al. (submitted 2000 to *Restoration Ecology*), EPA did not use the results from a recently restored portion of the wetland in this HRC valuation to avoid a downward bias in the species density results (and resultant higher restoration costs). The results from this sampling effort are presented in Table G5-13 for the species impinged and entrained at Pilgrim and identified as benefitting most from tidal wetlands restoration.

Table G5-13: Abundance Estimates from the Unrestricted Tidal Wetlands at Galilee for Fish Species Impinged or Entrained at Pilgrim that Would Benefit Most from Tidal Wetland Restoration

Species	Sampling Technique	Fish Density Estimates in Unrestricted Tidal Wetlands (fish per m^2)		
		1997	1998	1999
American sand lance	throw trap	no obs.	no obs.	no obs.
Winter flounder	throw trap	no obs.	no obs.	no obs.
Atlantic silverside	throw trap	4.78	1.73	14.38
Grubby	throw trap	no obs.	no obs.	no obs.
Striped killifish	throw trap	4.35	3.50	12.40
Striped bass	throw trap	no obs.	no obs.	no obs.
Bluefish	throw trap	no obs.	no obs.	no obs.

Source: Raposa, in press.

Coggeshall Marsh, Prudence Island, Rhode Island

Discussions with Kenny Raposa of the Narragansett Estuarine Research Reserve (NERR) revealed that additional fish abundance estimates from tidal wetland sampling were available for the Coggeshall Marsh located on Prudence Island in the NERR. These abundance estimates were based on sampling conducted in July and September 2000. The sampling of the Coggeshall tidal wetland was conducted using 1 m^2 throw traps in the tidal creeks and pools of the wetland during ebb tide after the wetland surface had drained (personal communication, K. Raposa, Narragansett Estuarine Research Reserve, 2001). The sampling results from this effort are presented in Table G5-14 for the species impinged and entrained at Pilgrim and identified as benefitting most from tidal wetlands restoration.

Table G5-14: Abundance Estimates from the Unrestricted Tidal Wetlands at Coggeshall for Fish Species Impinged or Entrained at Pilgrim that Would Benefit Most from Tidal Wetland Restoration

Species	Sampling Technique	Fish Density Estimates in Tidal Wetlands (fish per m^2)	
		July 2000	September 2000
American sand lance	throw trap	no obs.	no obs.
Winter flounder	throw trap	0.10	0.10
Atlantic silverside	throw trap	0.17	0.07
Grubby	throw trap	no obs.	no obs.
Striped killifish	throw trap	2.40	0.53
Striped bass	throw trap	no obs.	no obs.
Bluefish	throw trap	no obs.	no obs.

Winter flounder data from Rhode Island Juvenile Finfish Survey at the Chepiwanoxet and Wickford sample locations

The Rhode Island juvenile finfish survey samples 18 locations once a month from June through October using a beach seine that is approximately 60 m (200 ft) long and 3 m (10 ft) wide/deep. The sampled sites vary from cobble reef to sandy substrate. Winter flounder prefer shallow water habitats with sandy substrate, and such substrate conditions can be restored in large coastal ponds or pools. Therefore, EPA obtained winter flounder abundance estimates from this survey (personal communication, C. Powell, Rhode Island Department of Environmental Management, 2001). The two sample locations with the highest average winter flounder abundance estimates for 1990 through 2000 were in coastal ponds with sandy bottoms. The average abundance estimates from these sites, Chepiwanoxet and Wickford, are presented in Table G5-15 for samples taken from 1990 through 2000.

Table G5-15: Average Winter Flounder Abundance, 1990-2000, at the Sites with the Highest Results from the Rhode Island Juvenile Finfish Survey

Species	Sampling Technique	Fish Density Estimates in Sandy Nearshore Substrate (fish per m^2)	
		Chepiwanoxet 1990-2000	Wickford 1990-2000
Winter flounder	beach seine	0.09	0.20

Winter flounder data from Rhode Island Coastal Pond Survey at Narrow River, Winnapaug Pond, and Point Judith Pond

In addition to its juvenile finfish survey, Rhode Island conducts a survey of fish in its coastal ponds. The habitat characteristics in these locations are similar to those that can be restored through tidal wetland restoration. This survey includes winter flounder.

A Rhode Island coastal pond survey has been conducted since 1998 at the same 16 sites using an approximately 40 m (130 ft) long seine that is set offshore by boat and then drawn in from shore by hand. For each site, the average of the three highest winter flounder capture results for 1998-2001, adjusted for the average area covered by each seine set, is presented in Table G5-16 (personal communication, J. Temple, Rhode Island Division of Fish and Wildlife, 2002).

Table G5-16: Average Winter Flounder Abundance for 1998-2001 at the Sites with the Highest Results from the Rhode Island Coastal Pond Survey

Species	Sampling Technique	Average Winter Flounder Density Estimates in Sandy Nearshore Substrate (fish per m^2)		
		Narrow River	Winnapaug Pond	Point Judith Pond
Winter flounder	beach seine	0.32	0.21	0.21

G5-5.2.2 Adjusting tidal wetland sampling results to estimate annual average increase in production of age 1 fish

The sampling abundance results presented in Section G5-5.2.1 were adjusted to account for the following:

- sampling efficiency
- conversion to the age 1 life stage
- differences in production between restored and undisturbed tidal wetlands
- the impact of sampling timing and location.

Sampling efficiency

As previously described, sampling efficiency adjustments are made to account for the fact that sampling techniques do not capture all fish that are present. Jordan et al. (1997) estimated that 1 m^2 throw traps have a sampling efficiency of 63 percent. Therefore, EPA applied an adjustment factor of 1.6 (i.e., 1.0/0.63) to tidal wetland abundance data that were collected with 1 m^2 throw traps.

The sampling efficiencies of bottomless lift nets are provided in Rozas (1992) as 93 percent for striped mullet (*Mugil cephalus*), 81 percent for gulf killifish (*Fundulus grandis*), and 58 percent for sheepshead minnow (*Cyprinodon variegatus*). The average of these three sampling efficiencies is 77 percent (adjustment factor of 1.3, or 1.0/0.77) and is assumed to be applicable to species lost to I&E at Pilgrim.

Lastly, although specific studies of the sample efficiency of a beach seine net were not identified, an estimated range of 50 percent to 75 percent was provided by the staff involved with the Rhode Island coastal pond survey (personal communication, J. Temple, Rhode Island Division of Fish and Wildlife, 2002). Using the lower end of this range as a cost reducing assumption, EPA applied a sample efficiency adjustment factor of 2.0 (i.e., 1.0/0.5) for the abundance estimates for both the Rhode Island juvenile finfish survey and the Rhode Island coastal pond survey.

Conversion to age 1 life stage

The sampling techniques described in Section G5-5.2.1 are intended to capture juvenile fish (personal communication, K. Raposa, Narragansett Estuarine Research Reserve, 2001). That juvenile fish were the dominant age class taken was confirmed by the researchers involved in these efforts (personal communication, K. Raposa, Narragansett Estuarine Research Reserve, 2001; personal communication, C. Powell, Rhode Island Department of Environmental Management, 2001; personal communication, J. Temple, Rhode Island Division of Fish and Wildlife, 2001). As a result, the sampling results presented in Section G5-5.2.1 required adjustment to account for expected mortality between the juvenile and age 1 life stages. The information used to develop these survival rates and the final life stage adjustment factors are presented in Table G5-17.

Table G5-17: Life Stage Adjustment Factors for Pilgrim Species — Tidal Wetland Restoration

Species	Oldest Life Stage before Age 1 in the EAM	Estimated Survival Rate to Age 1	Life Stage Captured in Tidal Wetland Sampling Efforts	Estimated Survival Rate for Juveniles to Age 1
American sand lance	larvae	0.0298	juvenile	0.5149
Winter flounder	juvenile	0.2903	juvenile	0.2903
Atlantic silverside	larvae	0.0044	juvenile	0.5022
Grubby	larvae	0.0180	juvenile	0.5090
Striped killifish	larvae	0.0949	juvenile	0.5474
Striped bass[a]	juvenile	0.5361	juvenile	0.5361
Bluefish	juvenile	0.0103	juvenile	0.0103

[a] Information in the EAM model is available for two juvenile life stages for striped bass. The data for the older juvenile life stage were used.

Adjusting for differences between restored and undisturbed habitats

Restoring full tidal flows rapidly eliminates differences in fish populations between unrestricted and restored sites (Roman et al., submitted 2000 to *Restoration Ecology*), resulting in very similar species composition and density (Dionne et al., 1999; Fell et al., 2000; Warren et al., 2001). However, a lag can occur following restoration (Raposa, in press). Given uncertainty over the length of this lag, and the rate at which increased productivity in a restored tidal wetland approaches its long-term steady state, EPA incorporated an adjustment factor of 1.0 to signify that no quantitative adjustment was made consistent with its approach of incorporating cost reducing assumptions.

Adjusting sampled abundance for timing and location of sampling

At high tide, fish in a tidal wetland have access to the full range of habitats, including the flooded vegetation, ponds, and creeks that discharge into or drain the wetland. In contrast, at low tide, fish are restricted to tidal pools and creeks. Therefore, sampling conducted at low tide represents a larger area of tidal wetlands than the sampled area. EPA therefore divided the abundance estimates based on samples taken at low tide by the inverse of the proportion of subtidal habitat to total wetland habitat. In contrast, no adjustment was applied to abundance estimates based on samples such as those from lift nets or seines, taken at high tide or in open water offshore. The site-specific adjustment factors in Table G5-18 were based on information regarding the proportion of each tidal wetland that is subtidal habitat (personal communication, K. Raposa, Narragansett Estuarine Research Reserve, 2001).

Table G5-18: Adjustment Factors for Tidal Wetland Sampling Conducted at Low Tide

Tidal Wetland	Ratio of Open Water (creeks, pools) to Total Habitat in the Wetland	Adjustment Factor
Sachuest Marsh	0.055	18.2
Galilee Marsh	0.084	11.9
Coggeshall Marsh	0.052	19.2

G5-5.2.3 Final estimates of annual average age 1 fish production from tidal wetland restoration

Table G5-19 presents the final estimates of annual increased production of age 1 fish resulting from tidal wetland restoration for species impinged and entrained at Pilgrim and identified as benefitting most from tidal wetland restoration.

Table G5-19: Final Estimates of the Annual Increase in Production of Age 1 Equivalent Fish per Square Meter of Restored Tidal Wetland for Fish Species Impinged or Entrained at Pilgrim that Would Benefit Most from Tidal Wetland Restoration

Species	Source of Initial Species Density Estimate	Sampling Location and Date[a]	Reported/Calculated Species Density Estimate per m^2 of Tidal Wetland	Sampling Efficiency Adjustment Factor	Life Stage Adjustment Factor	Restored Habitat Service Flow Adjustment Factor	Sampling Time and Location Adjustment Factor	Increased Production of Age 1 Fish per m^2 of Restored Tidal Wetland[b c]
American sand lance	Unknown							
Winter flounder	Raposa pers comm 2001	NERR — Prudence Isl. Coggeshall - July 2000	0.10	1.6	0.2903	1	19.23	0.00
	Raposa pers comm 2001	NERR — Prudence Isl. Coggeshall — Sept. 2000	0.10	1.6	0.2903	1	19.23	0.00
	C Powell pers comm 2001	Chepiwanoxet average 1990-2000 (seine)	0.09	2.0	0.2903	1	1.00	0.05
	C Powell pers comm 2001	Wickford average 1990-2000 (seine)	0.20	2.0	0.2903	1	1.00	0.12
	J. Temple pers comm 2002	Narrow River average 1998-2001 (seine)	0.32	2.0	0.2903	1	1.00	0.19
	J. Temple pers comm 2002	Winnapaug Pond average 1998-2001 (seine)	0.21	2.0	0.2903	1	1.00	0.12
	J. Temple pers comm 2002	Point Judith Pond average 1998-2001 (seine)	0.21	2.0	0.2903	1	1.00	0.12
	Species average							**0.09**
Atlantic silverside	Roman et al., submitted 2000 to *Restoration Ecology*	Sachuest Point — 1997	1.23	1.6	0.5022	1	18.18	0.05
	Roman et al., submitted 2000 to *Restoration Ecology*	Sachuest Point — 1998	0.20	1.6	0.5022	1	18.18	0.01
	Roman et al., submitted 2000 to *Restoration Ecology*	Sachuest Point — 1999	0.07	1.6	0.5022	1	18.18	0.00
	Raposa pers comm 2001	NERR — Prudence Isl. Coggeshall - July 2000	0.17	1.6	0.5022	1	19.23	0.01
	Raposa pers comm 2001	NERR — Prudence Isl. Coggeshall — Sept. 2000	0.07	1.6	0.5022	1	19.23	0.00
	Raposa, in press	Galilee Marsh — 1997	4.78	1.6	0.5022	1	11.90	0.32

Table G5-19: Final Estimates of the Annual Increase in Production of Age 1 Equivalent Fish per Square Meter of Restored Tidal Wetland for Fish Species Impinged or Entrained at Pilgrim that Would Benefit Most from Tidal Wetland Restoration (cont.)

Species	Source of Initial Species Density Estimate	Sampling Location and Date[a]	Reported/Calculated Species Density Estimate per m^2 of Tidal Wetland	Sampling Efficiency Adjustment Factor	Life Stage Adjustment Factor	Restored Habitat Service Flow Adjustment Factor	Sampling Time and Location Adjustment Factor	Increased Production of Age 1 Fish per m^2 of Restored Tidal Wetland[b]
Atlantic silverside	Raposa, in press	Galilee Marsh — 1998	1.73	1.6	0.5022	1	11.90	0.12
	Raposa, in press	Galilee Marsh — 1999	14.38	1.6	0.5022	1	11.90	0.97
	Species average							**0.19**
Grubby	Unknown							
Striped killifish	Roman et al., submitted 2000 to *Restoration Ecology*	Sachuest Point — 1997	0.70	1.6	0.5474	1	18.18	0.03
	Roman et al., submitted 2000 to *Restoration Ecology*	Sachuest Point — 1998	0.17	1.6	0.5474	1	18.18	0.01
	Roman et al., submitted 2000 to *Restoration Ecology*	Sachuest Point — 1999	0.55	1.6	0.5474	1	18.18	0.03
	Roman et al., submitted 2000 to *Restoration Ecology*	Sachuest Point — 1998 (lift net)	0.01	1.3	0.5474	1	1.00	0.01
	Roman et al., submitted 2000 to *Restoration Ecology*	Sachuest Point — 1999 (lift net)	0.01	1.3	0.5474	1	1.00	0.01
	Raposa pers comm 2001	NERR — Prudence Isl. Coggeshall — July 2000	2.40	1.6	0.5474	1	19.23	0.11
Striped killifish	Raposa pers comm 2001	NERR — Prudence Isl. Coggeshall — Sept. 2000	0.53	1.6	0.5474	1	19.23	0.02
	Raposa, in press	Galilee Marsh — 1997	4.35	1.6	0.5474	1	11.90	0.32
	Raposa, in press	Galilee Marsh — 1998	3.50	1.6	0.5474	1	11.90	0.26

Table G5-19: Final Estimates of the Annual Increase in Production of Age 1 Equivalent Fish per Square Meter of Restored Tidal Wetland for Fish Species Impinged or Entrained at Pilgrim that Would Benefit Most from Tidal Wetland Restoration (cont.)

Species	Source of Initial Species Density Estimate	Sampling Location and Date[a]	Reported/Calculated Species Density Estimate per m^2 of Tidal Wetland	Sampling Efficiency Adjustment Factor	Life Stage Adjustment Factor	Restored Habitat Service Flow Adjustment Factor	Sampling Time and Location Adjustment Factor	Increased Production of Age 1 Fish per m^2 of Restored Tidal Wetland[b]
Striped killifish	Raposa, in press	Galilee Marsh — 1999	12.40	1.6	0.5474	1	11.90	0.91
	Species average							**0.17**
Striped bass	Unknown							
Bluefish	Unknown							

[a] Sampling results are based on collections using 1 m^2 throw traps unless otherwise noted.
[b] Calculated by multiplying the initial species density estimate by the sampling efficiency, life stage, and restored habitat service flow adjustment factors and dividing by the sampling time and location adjustment factor.
[c] Values of 0.00 presented in the table have an abundance of less than 0.005 fish per m^2 so do not appear in the rounding of results for purposes of presentation.

G5-5.3 Estimates of Increased Age 1 Fish Production from Artificial Reef Development

Constructing reefs of cobbles or small boulders was the preferred restoration alternative for a number of species impinged or entrained at Pilgrim. These species generally favor habitats with interstices that provide forage and shelter from predators. The species that would benefit most from artificial reef development are identified in Table G5-20, along with information on their annual average I&E losses for the period 1974-1999.

Table G5-20: Species with Quantified Age 1 Equivalent I&E Losses at Pilgrim that Would Benefit Most from Artificial Reef Development

Species	Annual Average I&E Loss of Age 1 Equivalents (1974-1999)	Percentage of Total I&E Losses across All Fish Species
Rock gunnel	4,862,872	33.73%
Radiated shanny	1,644,456	11.41%
Cunner	993,911	6.89%
Sculpin species	734,773	5.10%
Tautog	1,076	0.01%
Total	8,237,088	57.14%

EPA could not find any studies that provided direct estimates of increased fish production resulting from artificial reef development. Therefore, EPA used available fish abundance estimates in reef habitats as a proxy for production. The following subsections present these abundance estimates along with the adjustments made to convert life stages to age 1 equivalents and to account for habitat and sampling influences on the reported abundance estimates.

G5-5.3.1 Species abundance estimates in artificial reef habitats

Tautog data from juvenile finfish survey at Patience Island and Spar Island, Rhode Island

The Rhode Island juvenile finfish survey samples 18 locations once per month from June through October using a 60 m long beach seine that is approximately 3 m deep/wide. Among the sampled locations are two artificial cobble habitats, Spar Island and Patience Island, that have the highest average tautog abundance estimates (fish per square meter) of the 18 locations for the 1990-2000 period (personal communication, C. Powell, Rhode Island Department of Environmental Management, 2001). These average abundance estimates are presented in Table G5-21.

Table G5-21: Tautog Abundance Estimates from the Rhode Island Juvenile Finfish Survey at the Two Locations with the Highest Average Values for the Period 1990-2000

Species	Sampling Technique	Fish Density Estimates in Nearshore Cobble Reef Habitats (fish per m^2)	
		Patience Island	Spar Island
Tautog	beach seine	0.028	0.031

Cunner from the Pilgrim facility intake breakwater (Plymouth, Massachusetts)

Lawton et al. (2000) estimated the size of the adult cunner population residing on the inner and outer breakwaters at the Pilgrim facility based on the results of a tagging study and baited traps during 1994 and 1995. The adult population estimates were reported as a central estimate with upper and lower 95 percent confidence intervals. EPA converted these estimates into density estimates (adult fish per square meter of habitat) with information on the size of the habitat in each location (personal communication, M. Camisa, Massachusetts Division of Marine Fisheries, 2001). The estimated adult cunner populations, the size of the breakwater habitats, and the resulting adult cunner abundance estimates for the central and upper 95 percent confidence interval estimate are presented in Table G5-22.

Table G5-22: Adult Cunner Abundance Estimates in Reef Habitat of the Inner and Outer Breakwaters at the Pilgrim Facility

Location	Estimated Habitat Area (m^2)	Year	Adult Cunner Population Estimate		Assumed Adult Cunner Density Estimates (fish/m^2)	
			Central Estimate	Upper 95% CI Estimate	Based on Central Estimate	Based on Upper 95% CI Estimate
Outer breakwater	1,060	1994	3,628	4,265	3.42	4.02
		1995	5,833	7,569	5.50	7.14
		Average	**4,731**	**5,917**	**4.46**	**5.58**
Inner breakwater	992	1994	3,780	5,772	3.81	5.82
		1995	3,467	4,127	3.49	4.16
		Average	**3,624**	**4,950**	**3.65**	**4.99**
Average across inner and outer breakwaters					**4.06**	**5.29**

G5-5.3.2 Adjusting artificial reef sampling results to estimate annual average increase in production of age 1 fish

As with the other restoration alternatives, EPA made sampling efficiency, life stage conversion, and restored versus undisturbed habitat adjustments to production estimates for artificial reef habitats. These adjustments are discussed below.

Sampling efficiency

EPA incorporated the same sampling efficiency adjustment factor of 2.0 for the tautog abundance estimates developed from the Rhode Island juvenile finfish survey as was used in the sampling efficiency adjustments from this survey for winter flounder. The 2.0 adjustment factor represents the bottom range (cost reducing assumption) of a seine net's sampling efficiency (50 percent), based on the judgment of the current staff of Rhode Island's coastal pond fish survey (personal communication, J. Temple, Rhode Island Division of Fish and Wildlife, 2002).

The sampling efficiency of the baited traps and tagging procedure used in Lawton et al. (2000) was assumed to be 1.0, since the results of the study already incorporate sampling efficiency for cunner as reported.

Conversion to the age 1 equivalent life stage

The information used to develop life stage adjustment factors for juvenile fish to age 1 equivalents is presented in Table G5-23 for the species other than cunner impinged or entrained at Pilgrim and identified as benefitting most from artificial reef development (sampled cunner were mostly adults, as described below).

Table G5-23: Life Stage Adjustment Factors for Pilgrim Species — Artificial Reef

Species	Oldest Life Stage before Age 1 in the EAM	Estimated Survival Rate to Age 1	Sampled Life Stage	Estimated Survival Rate for Juveniles to Age 1
Rock gunnel	larvae	0.1416	juvenile	0.5708
Radiated shanny	larvae	0.0853	juvenile	0.5426
Sculpin spp.	larvae	0.0180	juvenile	0.5090
Tautog	larvae	0.0001	juvenile	0.5001

The Rhode Island juvenile finfish survey primarily captures juvenile tautog. However, the size distribution of cunner reported by Lawton et al. (2000) suggests that primarily adult fish were captured. Some of these cunner were most likely older than age 1. To convert the raw cunner numbers to age 1 equivalents, EPA used the same factor of 1.39 that was used in the EAM to convert the raw numbers of cunner impinged to age 1 equivalents.

Adjusting for differences between restored and undisturbed habitats

EPA incorporated an adjustment factor of 1.0 because no available information suggested that artificial reefs are used substantially less than natural reefs by the species listed in Table G5-20 and/or that significant delays in the use of artificial reefs follows their emplacement. To the extent lower levels of fish species use or delays in such use do occur with artificial reefs, incorporating an adjustment factor of 1.0 represents a cost-reducing assumption.

G5-5.3.3 Final estimates of increases in age 1 production for artificial reefs

Table G5-24 presents the final estimates of annual increased production of age 1 fish, based on the average across all sampling efforts, that would result from artificial reef development for species impinged or entrained at Pilgrim.

Table G5-24: Final Estimates of Annual Increased Production of Age 1 Equivalent Fish per Square Meter of Artificial Reef Developed for Pilgrim Species

Species	Source of Initial Species Density Estimate	Species Abundance Estimates (fish/m^2 reef)	Sampling Efficiency Adjustment Factor	Life Stage Adjustment Factor	Restored vs. Undisturbed Habitat Adjustment Factor	Expected Age 1 Increased Production (fish per m^2 artificial reef)
Rock gunnel	Unknown					
Radiated shanny	Unknown					
Cunner	Lawton et al. (2000), Plymouth MA	4.06[a]	1.0	1.39	1.0	5.64
Sculpin spp.	Unknown					
Tautog	RI juvenile finfish survey, 1990-2000: Patience Island	0.028	2.0	0.5001	1.0	0.03
	RI juvenile finfish survey, 1990-2000: Spar Island	0.031	2.0	0.5001	1.0	0.03
	Species average					**0.03**

[a] Average of the central population estimates for the inner and outer breakwaters.

G5-5.4 Estimates of Increased Species Production from Installed Fish Passageways

A habitat-based option for increasing the production of anadromous species is to increase their access to suitable spawning and nursery habitat by installing fish passageways at currently impassible barriers (e.g., dams). The anadromous species impinged or entrained at Pilgrim that would benefit most from fish passageways are presented in Table G5-25, along with information on their annual average I&E losses for the period 1974-1999.

Table G5-25: Anadromous Fish Species Impinged or Entrained at Pilgrim that Would Benefit Most from Fish Passageways

Species	Annual Average I&E Loss of Age 1 Equivalents (1974-1999)	Percentage of Total I&E Losses across All Fish Species
Rainbow smelt	1,330,022	9.23%
Alewife	4,343	0.03%
Blueback herring	703	0.00%
White perch	73	0.00%
Total	**1,335,141**	**9.26%**

G5-5.4.1 Abundance estimates for anadromous species

No studies provided direct estimates of increased production of anadromous fish attributable to the installation of a fish passageway. Thus, EPA based increased production estimates on abundance estimates from anadromous species monitoring programs in Massachusetts and Rhode Island, combined with an estimate of the average increase in suitable spawning habitat that would be provided upstream of the current impassible obstacles following the installation of fish passageways.

Anadromous species abundance in Massachusetts and Rhode Island spawning/nursery habitats

Information on the abundance of anadromous species in spawning/nursery habitat in Massachusetts was available only for a select number of alewife spawning runs in the area around the Cape Cod canal, including locations in Massachusetts Bay and Buzzards Bay (personal communication, K. Reback, Massachusetts Division of Marine Fisheries, 2001). Alewife abundance information was also available for the spawning runs at the Gilbert Stuart and Nonquit locations in Rhode Island. These runs are almost exclusively alewives, despite being reported as runs of river herring (i.e., blueback herring and alewives; personal communication, P. Edwards, Rhode Island Department of Environmental Management, 2001). The size of these alewife runs and the associated abundance estimates (number of fish per acre) in available spawning/nursery habitat are presented in Table G5-26.

The Mattapoisett system has low spawning habitat utilization by alewives because of continuing recovery of the system (personal communication, K. Reback, Massachusetts Division of Marine Fisheries, 2001). Therefore, the Mattapoisett River values were omitted. This raised the production estimates for fish passageways and reduced the restoration costs for implementing sufficient fish passageways.

Table G5-26: Average Run Size and Density of Alewives in Spawning Nursery Habitats in Select Massachusetts Waterbodies

Waterbody	Average Alewife Run Size (number of fish)	Average Number of Fish per Acre of Spawning/Nursery Habitat
Back River (MA) (12 year average)	373,608	766
Mattapoisett River[a] (12 year average)	66,457	90
Monument River (MA) (12 year average)	367,521	811
Nonquit system (RI) (1999-2001 average)	192,173	951
Gilbert Stuart system (RI) (1999-2001 average)	311,839	4,586
Average across all sites presented		1,441
Average without Mattapoisett River		1,778

[a] The Mattapoisett River is currently in recovery and production has been increasing in recent years (personal communication, K. Reback, Massachuset Division of Marine Fisheries, 2001).

Average size of spawning/nursery habitat that would be accessed with the installation of fish passageways

Anadromous fisheries staff in Massachusetts revealed that approximately 5 acres of additional spawning/nursery habitat would become accessible for each average passageway installed (personal communication, K. Reback, Massachusetts Division of Marine Fisheries, 2001). This estimate reflects the fact that previous projects have already provided access to most of the available large spawning/nursery habitats.

G5-5.4.2 Adjusting anadromous run sampling results to estimate annual average increase in production of age 1 fish

As with the other restoration alternatives, EPA considered a number of adjustment factors. However, information was much more limited upon which to base these adjustments. Adjustments to convert returning alewives to age 1 equivalents and to account for sampling efficiency were not incorporated (i.e., assumed to be 1.0) because of a lack of information. In addition, nothing suggested a basis for adjustments based on differences between existing and new spawning habitat accessed via fish passageways or a lag in use of spawning habitat once access is provided, so EPA used an adjustment factor of 1.0.

G5-5.4.3 Final estimates of annual age 1 equivalent increased species production

The density of anadromous species in their spawning/nursery habitat, the average increase in spawning/nursery habitat from installation of fish passageways, and adjustment factors are presented in Table G5-27.

Table G5-27: Estimates of Increased Age 1 Fish for Fish Species Impinged or Entrained at Pilgrim that Would Benefit Most from Installation of Fish Passageways

Species	Source of Initial Species Density Estimate	Species Density Estimate in Spawning/Nursery Habitat (fish per acre)	Number of Additional Spawning/Nursery Habitat Acres per New Passageway	Life Stage Adjustment Factor	New vs. Existing Habitat Adjustment Factor	Calculated Annual Increase in Age 1 Fish per New Passageway Installed[a]
Rainbow smelt	Unknown					
Alewife	Mattapoisett River — (K. Reback MA DMF pers. comm, 2001)	90	5	1	1	452
	Monument River — (K. Reback MA DMF pers. comm, 2001)	811	5	1	1	4,054
	Back River — (K. Reback MA DMF pers. comm, 2001)	766	5	1	1	3,828
	Nonquit river system — (P. Edwards, RI DEM, pers comm, 2001)	951	5	1	1	4,757
	Gilbert Stuart river system — (P. Edwards, RI DEM, pers comm, 2001)	4,586	5	1	1	22,929
	Species average (excluding Mattapoisett River)[b]					**8,892**
Blueback herring	Unknown					
White perch	Unknown					

[a] This value is the product of the values in the five data fields. Species density estimates rounded for presentation.
[b] As previously noted, the Mattapoisett results are excluded in calculating the species average for alewife because the low density estimates are attributable to the system recovering from previous stressors.

G5-5.5 Estimates of Remaining Losses in Age 1 Fish Production from Species Without an Identified Habitat Restoration Alternative

Some species lost to I&E at Pilgrim do not benefit directly and/or predictably from SAV restoration, tidal wetland restoration, artificial reef construction, or improved passageways because the species are pelagic, spawn in deep water, or spawn in unknown or poorly understood habitats. The species impinged or entrained at Pilgrim that fall into this category are listed in Table G5-28, along with their annual average I&E losses for 1974-1999.

Table G5-28: Fish Species Impinged or Entrained at Pilgrim that Lack a Habitat Restoration Alternative

Species	Average Annual I&E Loss of Age 1 Equivalent Organisms (1974-1999)	Percentage of Total I&E Losses for All Finfish or Shellfish Species
Finfish		
Fourbeard rockling	411,191	2.85%
Atlantic herring	29,079	0.20%
Windowpane	17,542	0.12%
Atlantic menhaden	14,270	0.10%
Atlantic mackerel	6,662	0.05%
Searobin	3,767	0.03%
Red hake	1,774	0.01%
Lumpfish	1,297	0.01%
Butterfish	399	0.00%
American plaice	221	0.00%
Scup	114	0.00%
Little skate	78	0.00%
Bay anchovy	18	0.00%
Hogchoker	2	0.00%
Total	**486,414**	**3.37%**
Shellfish		
Blue mussels	160,000,000,000[a]	100%

[a] Rounded to the nearest billion.

Despite the magnitude of I&E losses for these species, it was beyond the scope of this Section 316(b) HRC analysis to develop quantitative estimates of the increased production of age 1 fish and shellfish for these species through habitat restoration alternatives.

G5-6 Step 6: Scaling Preferred Restoration Alternatives

The following subsections calculate the required scale of implementation for each of the preferred restoration alternatives for each species. The quantified I&E losses are divided by the estimates of the increased fish production, giving the total amount of each restoration needed to offset I&E losses for each species.

G5-6.1 Submerged Aquatic Vegetation Scaling

The information used to scale SAV restoration is presented in Table G5-29.

Table G5-29: Scaling of SAV Restoration Species Impinged or Entrained at Pilgrim			
Species	**Annual Average I&E Loss of Age 1 Equivalents (1974-1999)**	**Best Estimate of Increased Production of Age 1 Fish per 100 m^2 of Revegetated Substrate (rounded)**	**Number of 100 m^2 Units of Revegetated SAV Required to Offset Estimated Average Annual I&E Loss**
Northern pipefish	118	2.50	47
Threespine stickleback	118	19.29	6
Atlantic cod	2,439	Unknown	Unknown
Pollock	525	Unknown	Unknown
Assumed units of implementation required to offset I&E losses for all of these species			**47**

G5-6.2 Tidal Wetlands Scaling

The information used to scale tidal wetland restoration is presented in Table G5-30.

Table G5-30: Scaling of Tidal Wetland Restoration for Species Impinged or Entrained at Pilgrim			
Species	**Annual Average I&E Loss of Age 1 Equivalents (1974-1999)**	**Best Estimate of Increased Production of Age 1 Fish per m^2 of Restored Tidal Wetland (rounded)**	**Number of m^2 Units of Restored Tidal Wetland Required to Offset Estimated Average Annual I&E loss[a]**
Winter flounder	210,715	0.09	2,429,812
Atlantic silverside	25,929	0.19	139,539
Striped killifish	90	0.17	527
American sand lance	4,116,285	Unknown	Unknown
Grubby	879	Unknown	Unknown
Striped bass	9	Unknown	Unknown
Bluefish	2	Unknown	Unknown
Assumed units of implementation required to offset I&E losses for all of these species			**2,429,812**

[a] A restored wetland area refers to an area in a currently restricted tidal wetland where invasive species (e.g., *Phragmites* spp.) have overtaken salt tolerant tidal marsh vegetation (e.g., *Spartina* spp.) and that is expected to revert to typical tidal marsh vegetation once tidal flows are returned. Waterways adjacent to these vegetated areas are also included in calculating the potential area that could be restored in a tidal wetland.

G5-6.3 Reef Scaling

The information used to scale artificial reef development is presented in Table G5-31.

Table G5-31: Scaling of Artificial Reef Development for Species Impinged or Entrained at Pilgrim			
Species	**Annual Average I&E Loss of Age 1 Equivalents (1974-1999)**	**Best Estimate of Increased Production of Age 1 Fish per m^2 of Artificial Reef (rounded)**	**Number of m^2 Units of Artificial Reef Surface Habitat Required to Offset Estimated Average Annual I&E Loss**
Cunner	993,911	5.64	176,218
Tautog	1,076	0.03	36,699
Rock gunnel	4,862,872	Unknown	Unknown
Radiated shanny	1,644,456	Unknown	Unknown
Sculpin species	734,773	Unknown	Unknown
Assumed units of implementation required to offset I&E losses for all of these species			**176,218**

G5-6.4 Anadromous Fish Passage Scaling

The information used to scale fish passageway installation is presented in Table G5-32.

Table G5-32: Scaling of Anadromous Fish Passageways for Species Impinged or Entrained at Pilgrim

Species	Annual Average I&E Loss of Age 1 Equivalents (1974-1999)	Best Estimate of Increased Production of Age 1 Fish per Passageway Installed (rounded)	Number of New Fish Passageways Required to Offset Estimated Average Annual I&E Loss
Alewife	4,343	8,892	0.49
Rainbow smelt	1,320,022	Unknown	Unvalued
Blueback herring	703	Unknown	Unvalued
White perch	73	Unknown	Unvalued
Assumed units of implementation required to offset I&E losses for all of these species			**0.49**

G5-7 Unit Costs

The seventh step of the HRC valuation is to develop unit cost estimates for the restoration alternatives. Unit costs account for all the anticipated expenses associated with the actions required to implement and maintain restoration. Unit costs also include the cost of monitoring to determine if the scale of restoration is sufficient to provide the anticipated increase in the production of age 1 fish per unit of restored habitat.

The standard HRC costing approach generally develops an estimate of the amount of money that would be required up front to cover all restoration costs over the relevant timeframe for the project. Hence, HRC accounting procedures generally consider interest earnings on money not immediately spent, and also factor in anticipated inflation for expenses to be incurred in the future. EPA used HRC costs as a proxy for “benefits” which are then compared to costs in the cost-benefit analysis chapter. Therefore, the Agency reinterpreted the standard HRC costing approach to make it consistent with the annualized costs used in the costing chapter of the EBA.

For this analysis, EPA annualized the HRC costs by separating the initial program outlays (one time expenditures for land, technologies, etc.) from the recurring annual expenses (e.g., for monitoring). The initial program outlays were treated as a capital cost and annualized over a 20-year period at a 7 percent interest rate. EPA then estimated the present value (PV), using a 7 percent interest rate, of the annual expenses for the 10 years of monitoring of increased fish production that are incorporated in the design of each of the habitat restoration alternatives. This PV was then annualized over a 20 year period, again using a 7 percent interest rate. This process effectively treats the monitoring expenses associated with the habitat restoration alternatives consistently with the annual operating and maintenance costs presented in the costing, economic impact, and cost-benefit analysis chapters. The annualized monitoring costs were then added to the annualized cost of the initial program outlays to calculate a total annualized cost for the habitat restoration alternative.

The following subsections present the cost components for the habitat restoration alternatives in this HRC along with the estimates of the annualized costs for implementation costs (i.e., one-time outlays), monitoring costs, and implementation and monitoring costs combined (all costs presented in year 2000 dollars).

G5-7.1 Unit Costs of SAV Restoration

EPA expressed annualized unit cost estimates for 100 m^2 of SAV habitat to provide a direct link to the increased fish production estimates for SAV restoration based on information from a number of completed and ongoing projects. The following subsections describe the development of the annualized implementation and monitoring costs for SAV restoration.

G5-7.1.1 Implementation costs

Save the Bay has a long history of SAV habitat assessment and restoration in Narragansett and Mount Hope Bays. A Save the Bay SAV restoration project begun in the summer of 2001 involved transplanting eelgrass to revegetate 16 m^2 of habitat at each of three sites in Narragansett Bay. EPA used cost information from this project to develop unit cost estimates for implementing SAV restoration per 100 m^2 of revegetated habitat.

Save the Bay's cost proposal estimated that $93,128 would be required to collect and transplant eelgrass shoots from donor SAV beds over 48 m^2 of revegetated habitat. These costs include collecting and transplanting the SAV shoots to provide an initial density of 400 shoots per revegetated square meter of substrate. Averaged over the 48 m^2 of habitat being revegetated, this provides an average unit cost of $1,940 per m^2. The unit costs comprise the following categories:

- labor: 70.7 percent (includes salaried staff with benefits, consultants, and accepted rates for volunteers)
- boats: 15.2 percent (expenses for operating the boat for the collecting and transplanting)
- materials and equipment: 9.6 percent
- overhead: 4.6 percent (calculated as a flat percentage of the labor expenses for the salaried staff).

Contingency expenses were set at 10 percent ($194 per m^2). The costs of identifying and evaluating the suitability of potential restoration sites were set at 1 percent ($19 per m^2). No costs were added for maintaining the service flows provided by the project, because SAV restoration requires little direct maintenance.

Costs were also adjusted to account for natural growth and spreading from the original transplant sites to the bare spots between transplants (Short et al., 1997). For example, Dr. Frederick Short (University of New Hampshire's Jackson Estuarine Laboratory) planted between 120 and 130 TERFS (Transplanting Eelgrass Remotely with Frame Systems), each 1 m^2, in each acre of seabed to be revegetated at a SAV restoration site (personal communication, P. Colarusso, U.S. EPA Region 1, 2002). Assuming complete coverage over time, this results in a ratio of plantings to total coverage of between 1:31 (130 1 m^2 TERFS / 4,047 m^2 per acre) and 1:34 (120 1 m^2 TERFS / 4,047 m^2 per acre).

However, the initially bare areas between transplants do not revegetate immediately and the unit costs need to be adjusted accordingly. Therefore, EPA assumed that the area covered with SAV would double each year. Under this assumption, the entire restoration area would be completely covered with SAV in the sixth year of the restoration project. Using the habitat equivalency analysis (HEA) method (Peacock, 1999), the present value of the natural resource service flows from the SAV over the 6 year revegetation scenario is 90 percent of that provided by a scenario where the entire restoration area is instantaneously revegetated with transplanted shoots.[1] Therefore, EPA applied 90 percent of the 1:34 planting-to-coverage ratio, or 1:30 as an adjustment factor to Save the Bay's cost estimates to account for the expected spreading from transplanted sites to bare areas in a SAV restoration area. Table G5-33 presents the components of implementation unit cost for SAV restoration, incorporating this adjustment ratio in the last step.

Table G5-33: Implementation Unit Costs for SAV Restoration

Expense Category	Cost per m^2 of SAV Restored	Cost per 100 m^2 of SAV Restored
Direct restoration (shoot collection and transplant)	$1,940	$194,000
Contingency costs (10% of direct restoration)	$194	$19,400
Restoration site assessment (1% of direct restoration)	$19	$1,900
Subtotal without allowance for distribution of transplanted SAV shoots	$2,154	$215,400
Discounted planting to coverage ratio for transplanted SAV	30:1	30:1
Final implementation unit costs	$71.80	$7,180
Annualized implementation unit costs	$6.76	$676

[1] The HEA method provides a quantitative framework for calculating the present value of resource service flows that are expected/observed to change over time.

G5-7.1.2 Monitoring costs

SAV restoration monitoring improves the inputs to the HRC analysis by quantifying the impact of the SAV restoration on fish production/recruitment in the restoration area, and the rate of growth and expansion of the restored SAV bed, including whether areas need to be replanted. The most efficient way to achieve both of these goals would be for divers to evaluate the number of adult fish in the habitat and the vegetation density, combined with throw trap or drop trap sampling of juvenile fish using the habitat (Short et al., 1997). Diver-based monitoring minimizes damage to sites, expands the areas that can be sampled, and increases sampling efficiency compared to trawl-based monitoring (personal communication, J. Hughes, NOAA Marine Biological Laboratory, 2001).

Save the Bay provided hourly rates for the divers and captain (personal communication, A. Lipsky, Save the Bay, 2001), and the daily rate for the boat was based on rate information from NOAA's Marine Biological Laboratory in Woods Hole (personal communication, J. Hughes, NOAA, 2001). Because SAV monitoring costs will be significantly affected by the size, number, and distance between restored SAV habitats, large areas can be covered in a single day only when continuous habitats are surveyed. Smaller, disconnected habitats will require much more time to cover. Therefore, total monitoring costs are somewhat unpredictable. Unit costs for monitoring were therefore assumed to be equal to the initial per unit revegetation costs in terms of the up front funding that would be required to cover the 10 years of monitoring (i.e., $7,180). Under the typical HRC costing construct this was equivalent to a per unit monitoring expense in the first year of $787. This simplifying assumption is unbiased (i.e., it is not known or expected to over- or underestimate costs). The summary of the available SAV monitoring costs and the calculated annualized per unit monitoring cost based on an assumed annual expense of $787 per unit are presented in Table G5-34.

Table G5-34: Estimated Annual Unit Costs for a SAV Restoration Monitoring Program

Annual Expenditures			
Expense Category	**Quantity**	**Daily Rate**	**Total Cost**
Monitoring crew	3 (2 divers and boat captain/assistant)	$268	$804
Monitoring boat	1	$150	$150
Total daily rate			$954
Assumed annual cost for SAV monitoring per 100 m^2 restored habitat			$787
Annualized monitoring cost per 100 m^2 restored habitat			$557

G5-7.1.3 Total submerged aquatic vegetation restoration costs

Combining the annualized unit costs for implementation and monitoring, the total annualized cost for a 100 m^2 unit of SAV restoration is $1,234 (rounded to the nearest dollar).

G5-7.2 Unit Costs of Tidal Wetland Restoration

Many different actions may be needed to restore flows to a wetland site, and project costs can vary widely, depending on the actions taken and a number of site-specific conditions (e.g., salinity levels at proposed restoration sites). These issues are addressed in the following subsections, which present the development of the unit costs for tidal wetland restoration.

G5-7.2.1 Implementation costs

Costs for restoration of tidally restricted marshes depend heavily on the type of restriction that is impeding tidal flow into the wetland and the amount of degradation that has occurred as a result. Possible sources of the restriction in tidal flow include improperly designed or located roads, railroads, bridges, and dikes, all of which can eliminate tidal flows or restrict tidal flows via improperly sized openings. A compilation of tidally restricted salt marsh restoration projects in the Buzzards Bay watershed (Buzzards Bay Project National Estuary Program, 2001) describes restrictions and costs to return tidal flows to over 130 sites. These cost estimates include expenses for project design, permitting, and construction, and are estimated on a predictive cost equation that was fitted from the actual costs and budgets for a limited number of projects (Buzzards Bay Project National Estuary Program, 2001).

Staff involved in the Buzzards Bay assessment provided the current project database, which includes the following information (personal communication, J. Costa, Buzzards Bay National Estuary Program, 2001):

- nature of the tidal restriction
- estimated cost to address the tidal restriction
- size of the affected tidal wetland (in acres)
- acreage of the *Phragmites* in the tidally restricted wetland.

Public agencies undertook some of the work in the projects used to develop the cost estimation equation for the tidally restricted wetlands in the Buzzards Bay watershed. Because the costs from public agencies are generally lower than market prices (i.e., the price for the same work if completed by private contractors), EPA adjusted the cost estimates upward by a factor of 2.0, consistent with the adjustment recommended in the report (Buzzards Bay Project National Estuary Program, 2001) and discussions with project staff and others involved with tidal wetlands restoration programs in the area (personal communication, J. Costa, Buzzards Bay National Estuary Program, 2001; personal communication, S. Block, Massachusetts Executive Office of Environmental Affairs - Wetlands Restoration Program, 2001).

The adjusted total project costs from the Buzzards Bay project database were then divided by the reported acres of *Phragmites* in the wetland to calculate the cost per acre for restoring tidally restricted wetlands where *Phragmites* had replaced the salt tolerant vegetation characteristic of a healthy tidal wetland (sites with no reported acres of *Phragmites* were eliminated from consideration).[2] Table G5-35 summarizes costs based on the cost factor (an input in the cost estimation equation), type of restriction found at the site, and the number of *Phragmites* acres at the location. An alternative summary of these projects is presented in Table G5-36, where the projects are organized by acres of *Phragmites* at the site, not the current tidal restriction.

Combined, Tables G5-35 and G5-36 show significant variability in the per acre costs for tidal wetland restoration. Therefore, EPA incorporated the median cost of $71,000 per acre of tidal wetland restoration into the HRC valuation and calculation of the unit cost for tidal wetland restoration. Table G5-37 presents the final per acre implementation costs for tidal wetland restoration and the annualized equivalent implementation cost incorporated in this HRC. These costs include the median per acre restoration cost of $71,000 and a $750 per acre fee to reflect the assumed purchase price for this type of land based on the experience of purchases of similar types of land parcels by the Rhode Island Department of Environmental Management's Land Acquisition Group (personal communication, L. Primiano, Rhode Island Department of Environmental Management, 2001).

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[2] The adjustment of reported costs upward by a factor of 2.0 was made solely to reflect expected cost differences between private contractors and public agencies that might perform the work required to restore full tidal flows. Additional site specific factors, such as salinity levels, that may affect project costs by influencing the types of actions taken and/or the time to successful restoration of typical tidally influenced wetland vegetation at a project site have not been incorporated in this adjustment process.

Table G5-35: Salt Marsh Restoration Costs

Restriction Structure Class	Cost Factor	*Phragmites* Acres	Number of Sites	Cumulative *Phragmites* Acreage across sites	Average *Phragmites* Acreage	Total Private Cost[a]	Average Cost per *Phragmites* Acre Restored	Minimum Cost per *Phragmites* Acre Restored	Maximum Cost per *Phragmites* Acre Restored
culvert	0.5	acres < 1	16	6.59	0.41	$335,357	$50,889	$17,921	$578,081
culvert	0.5	1 < acres < 5	11	20.37	1.85	$242,496	$11,903	$3,242	$71,045
culvert	0.5	5 < acres < 10	1	8.56	8.56	$20,825	$2,434	$2,434	$2,434
dike	0.5	acres < 1	1	0.35	0.35	$13,211	$38,073	$38,073	$38,073
road	0.5	1 < acres < 5	1	1.67	1.67	$19,116	$11,447	$11,447	$11,447
culvert	1	acres < 1	31	13.26	0.43	$1,797,450	$135,585	$21,518	$10,490,647
culvert	1	1 < acres < 5	23	46.02	2.00	$1,225,745	$26,633	$5,312	$84,770
culvert	1	5 < acres < 10	2	16.43	8.22	$248,878	$15,144	$9,898	$22,608
culvert	1	10 < acres < 25	2	41.97	20.99	$91,451	$2,179	$1,919	$2,449
dike	1	10 < acres < 25	1	12.00	12.00	$6,053,000	$504,417	$504,417	$504,417
fill	1	acres < 1	1	0.12	0.12	$31,142	$251,146	$251,146	$251,146
road	1	acres < 1	1	0.10	0.10	$29,396	$293,958	$293,958	$293,958
road	1	1 < acres < 5	1	2.31	2.31	$35,231	$15,265	$15,265	$15,265
wall	1	acres < 1	2	0.96	0.48	$148,819	$154,697	$25,661	$5,936,752
bridge	3	acres < 1	8	5.12	0.64	$21,208,029	$4,140,576	$184,170	$13,418,293
bridge	3	1 < acres < 5	12	27.32	2.28	$27,704,691	$1,014,192	$184,048	$3,663,062
bridge	3	5 < acres < 10	2	11.01	5.51	$6,606,000	$599,946	$399,746	$800,545
bridge	3	10 < acres < 25	8	103.49	12.94	$92,094,000	$889,883	$56,300	$3,300,250
bridge	3	25 < acres < 50	4	157.28	39.32	$8,262,000	$52,529	$22,882	$105,968
bridge	3	50 < acres	1	113.00	113.00	$6,163,000	$54,540	$54,540	$54,540
railroad	4	acres < 1	1	0.41	0.41	$66,841	$163,826	$163,826	$163,826
railroad	4	1 < acres < 5	3	3.61	1.20	$1,078,692	$298,476	$208,033	$13,418,293

[a] Private costs were estimated by multiplying reported project costs by an adjustment factor of 2.0 to approximate the expense if all work was completed by private contractors.

Table G5-36: Average per Acre Cost of Restoring *Phragmites* in Buzzards Bay Restricted Tidal Wetlands, by Size Class of Site

Phragmites Acres	Number of Sites	Cumulative *Phragmites* Acreage across sites	Average Acreage	Total Private Cost	Average Cost per *Phragmites* Acre Restored (from total cost and acres)
acres < 1	61	26.91	0.44	$23,630,245	$878,121
1 < acres < 5	51	101.31	1.99	$30,305,971	$299,153
5 < acres < 10	5	36.00	7.20	$6,875,703	$190,992
10 < acres < 25	11	157.46	14.31	$98,238,451	$623,895
25 < acres < 50	4	157.28	39.32	$8,262,000	$52,529
50 < acres	1	113.00	113.00	$6,163,000	$54,540
Total	133	591.96	4.45	$173,475,370	$293,053 (median = $71,000)

Table G5-37: Implementation Costs per Acre of Tidal Wetland Restoration Incorporated in the HRC valuation

Implementation Cost Description	Source of Estimate	Cost
Restore tidal flows to restricted areas	Median of adjusted costs from Buzzards Bay project database	$71,000
Acquire tidal wetlands	Midpoint of range of paid for tidal wetlands by Rhode Island DEM	$750
Total one time implementation costs		$71,750
Annualized implementation costs		$6,758

G5-7.2.2 Monitoring costs

Neckles and Dionne (1999) present a sampling protocol, developed by a workgroup of experts, for evaluating nekton use in restored tidal wetlands. The sampling plan calls for different sampling techniques and frequencies to capture fish of various sizes in both creek and flooded marsh habitats of a tidal wetland. A summary of these recommendations is presented in Table G5-38.

Table G5-38: Sampling Guidelines for Nekton in Restored Tidal Wetlands

Sampling Location	Sampling Technique	Sampling Time	Sampling Frequency
Creeks (for small fish)	Throw traps	midtide	2 dates in August
Creeks (for larger fish)	Fyke net	slack tide	2 dates in August (same as for throw trap work) and 2 dates in spring
Flooded wetland surface	Fyke net	entire tide cycle	1 date in August

Source: Neckles and Dionne, 1999.

The sampling protocol suggests that one technician and two volunteers can provide the necessary labor. The estimated annual cost in the first year of monitoring is $1,600. This cost comprises $490 in labor for the three workers over 5 days (3 in August and 2 in the spring, with 8-hour days, $15 per hour for volunteers, and $30 per hour for the technician). The $1,100 in equipment costs includes two fyke nets at $500 each and two throw traps at $50 each (Neckles and Dionne, 1999). The annualized equivalent of these monitoring costs is $1,146 and is applied as a per-acre cost for monitoring in this HRC valuation.

G5-7.2.3 Total tidal wetland restoration costs

Combining the annualized per-acre implementation and monitoring costs for tidal wetland restoration results in an annualized per-acre cost for tidal wetland restoration of $7,904. This is equivalent to an annualized cost for tidal wetland restoration of $1.95 per m^2 of restored tidal wetland (4,047 m^2 = 1 acre) which is incorporated into this HRC for consistency with the estimates of increased fish production from tidal wetland restoration which are also expressed on a per m^2 basis.

G5-7.3 Artificial Reef Unit Costs

The unit cost estimates for developing and monitoring artificial reefs are based the construction and monitoring of six 30 ft x 60 ft reefs made of 5-30 cm diameter stone in Dutch Harbor, Narragansett Bay (personal communication, J. Catena, NOAA Restoration Center, 2001). While these reefs were constructed for lobsters, surveys of the Dutch Harbor reef have noted abundant fish use of the structures (personal communication, K. Castro, University of Rhode Island, 2001).

G5-7.3.1 Implementation costs

The summary cost information for the design and construction of the six reefs in Dutch Harbor, as it was received is presented in Table G5-39 (personal communication, J. Catena, NOAA Restoration Center, 2001).

Table G5-39: Summary Cost Information for Six Artificial Reefs in Dutch Harbor, Rhode Island

Project Component	Cost
Project design	not explicitly valued, received as in-kind services
Permitting	not explicitly valued, received as in-kind services
Interagency coordination	not explicitly valued, received as in-kind services
RFP preparation	not explicitly valued, received as in-kind services
Contract management	not explicitly valued, received as in-kind services
Baseline site evaluation	$12,280
Reef materials (600 yd^3 of 2-12 in. stone)	$12,000
Reef construction	$35,400
Total	$59,680

EPA converted these costs to cost per square meter of surface habitat. The cumulative surface area of the six reefs, assuming that the reefs have a sloped surface on both sides, and based on the volume of material used, is approximately 1,024 m^2. Dividing the total project costs by this surface area results in an implementation cost of $58/$m^2$ of artificial reef surface habitat with an equivalent annualized implementation cost of $5.49/$m^2$.

G5-7.3.2 Monitoring costs

Monitoring costs for the Dutch Harbor reefs were $140,000 over a 5 year period. Assuming this reflects an annual monitoring cost of $28,000, the equivalent annual monitoring cost is $27/$m^2$ of artificial reef surface habitat with an equivalent annualized cost of $19.36/$m^2$.

G5-7.3.3 Total artificial reef costs

Combining the annualized costs for implementation and monitoring of an artificial reef provides a total annualized cost of $24.85/$m^2$ which EPA used in the Pilgrim HRC valuation.

G5-7.4 Costs of Anadromous Fish Passageway Improvements

EPA developed unit costs for fish passageways from a series of budgets for prospective anadromous fish passageway installation, combined with information provided by staff involved with anadromous species programs in Massachusetts and

Rhode Island. The implementation, maintenance, and monitoring costs for a fish passageway are presented in the following subsections.

G5-7.4.1 Implementation costs

Projected costs for four new Denil type fish passageways on the Blackstone River at locations in Pawtucket and Central Falls, Rhode Island, provide the base for the implementation cost estimates for anadromous fish passageways (personal communication, T. Ardito, Rhode Island Department of Environmental Management, 2001). The reported lengths of the passageways in these projects ranged from 32 m to 82 m, with changes in vertical elevation ranging from slightly more than 4 m to approximately 10 m.

The average cost for these projects was $513,750 per project. The average cost per meter of passageway length was $10,300 and per meter of vertical elevation covered was $82,600. These estimates are consistent with the approximate values of $9,800 per meter of passageway length and $98,000 per vertical meter suggested by the U.S. Fish and Wildlife Service's regional Engineering Field Office (personal communication, D. Quinn, U.S. Fish and Wildlife Service, 2001). While all parties contacted noted that fish passageway costs are extremely sensitive to local conditions, EPA used the estimate of $513,750 as the basic implementation unit cost for installing an anadromous fish passage, assuming the characteristics of the four sites on the Blackstone River are representative of the conditions that would be found at other suitable locations for new passageways.

G5-7.4.2 Maintenance and monitoring costs

Maintenance requirements for the Denil fish passageway are minimal and generally consist of periodic site visits to remove any obstructions, typically with a rake or pole (personal communication, D. Quinn, U.S. Fish and Wildlife Service, 2001). Denil passageways located in Maine are still functioning after 40 years, so no replacement costs were considered as part of the maintenance for the structure. Monitoring a fish passageway consists of installing a fish counting monitor and retrieving its data.

A new fish passageway would be visited three times a week during periods of migration (personal communication, D. Quinn, U.S. Fish and Wildlife Service, 2001). Each site visit would require 2 hours of cumulative time during 8 weeks of migration. Volunteer labor costs of $15.39/hr incorporated in Save the Bay's SAV restoration proposal. Therefore, the annual cost for labor in the first year would be $740. The cost of a fish counter is $5,512, based on the average price of two fish counters listed by the Smith-Root Company (Smith-Root, 2001).

G5-7.4.3 Total fish passageway unit costs

In developing the unit costs for fish passageways it is first necessary to combine the expected cost of the passageway itself with the cost of the fish counter as these are both treated as initial one time costs. This combined cost is $519,262 which has an equivalent annualized cost of $48,914. The equivalent annualized cost for the anticipated $740 in labor expenses for monitoring is $523. The resulting combined annualized cost for a new Denil fish passageway that is incorporated in this HRC valuation is $49,438 (rounded to the nearest dollar).

G5-8 Total Cost Estimation

The eighth and final step in the HRC valuation is to estimate the total cost for the preferred restoration alternatives by multiplying the required scale of implementation for each restoration alternative by the complete annualized unit cost for that alternative. EPA made a potentially large cost reducing assumption: no additional HRC-derived benefits were counted in the total benefits figures for species for which habitat productivity data are not available. If this assumption is valid, then the cost of each valued restoration alternative (except water quality improvement and fishing pressure reduction, which were not valued) is sufficient to offset the I&E losses of all Pilgrim species that benefit most from that alternative. EPA then summed the costs of each restoration program to determine the total HRC-based annualized value of all Pilgrim losses (i.e., multiple restoration programs were required to benefit the diverse species lost at Pilgrim).

The total HRC estimates for the Pilgrim facility are provided in Table G5-40, along with the species requiring the greatest level of implementation of each restoration alternative to offset I&E losses from among those for which information was identified that allowed for the development of estimates of increased fish production following implementation of the restoration alternative.

Table G5-40: Total HRC Estimates for Pilgrim I&E Losses

Preferred Restoration Alternative	Species Benefitting from the Restoration Alternative: Species	Species Benefitting from the Restoration Alternative: Average Annual I&E Loss of Age 1 Equivalents	Required Units of Restoration Implementation[a]	Units of Measure for Preferred Restoration Alternative	Total Annualized Unit Cost	Total Annualized Cost
Restore SAV	Northern pipefish	118	**47**	100 m^2 of directly revegetated substrate	$1,233.50	$57,975
	Threespine stickleback	118	6			
	Atlantic cod	2,439	Unknown			
	Pollack	525	Unknown			
Restore tidal wetland	Winter flounder	210,715	**2,429,812**	m^2 of restored tidal wetland	$1.95	$4,746,249
	Atlantic silverside	25,929	139,539			
	Striped killifish	90	527			
	American sand lance	4,116,285	Unknown			
	Grubby	879	Unknown			
	Striped bass	9	Unknown			
	Bluefish	2	Unknown			
Create artificial reefs	Cunner	993,911	**176,218**	m^2 of reef surface area	$24.85	$4,379,701
	Tautog	1,076	36,699			
	Rock gunnel	4,862,872	Unknown			
	Radiated shanny	1,644,456	Unknown			
	Sculpin spp.	734,773	Unknown			
Install fish passageways	Alewife	4,343	**0.49**	New fish passageway	$49,437.64	$49,438[b]
	Rainbow smelt	1,330,022	Unknown			
	Blueback herring	703	Unknown			
	White perch	73	Unknown			
Species not valued	Blue mussel	160,000,000,000	Unknown for all	Restoration measures unknown — survival and reproduction may be improved by other regional objectives such as improving water quality or reducing fishing pressure if projects can be identified and are permanent improvements.	N/A	N/A
	Fourbeard rockling	411,191				
	Atlantic herring	29,079				
	Windowpane	17,542				
	Atlantic menhaden	14,270				
	Atlantic mackerel	6,662				
	Searobin	3,767				
	Red hake	1,774				
	Lumpfish	1,297				
	Butterfish	399				
	American plaice	221				
	Scup	114				
	Little skate	78				
	Bay anchovy	18				
	Hogchoker	2				
Total annualized HRC valuation						$9,233,362

[a] Numbers of units used to calculate costs for each restoration alternative are shown in bold and have been rounded to the nearest unit.
[b] Anadromous fish passageways must be implemented in whole units, and increased production data are lacking for most affected anadromous species. Therefore, one new passageway was assumed to be warranted.

To facilitate comparisons with the costs of alternative control technologies that could be considered to reduce I&E losses at the Pilgrim facility, the combined I&E losses are broken down with separate values developed for the losses to impingement and entrainment (Tables G5-41 and G5-42 respectively).

A result of interest from Tables G5-41 and G5-42 is that the sum of the valuations of the impingement and entrainment losses is close to the valuation when the I&E losses were combined ($9.6 million versus $9.2 million). This consistency is not a given when the HRC process is used to address I&E losses separately from I&E losses combined because different species may drive the scaling of the restoration alternatives when I&E losses are treated separately (e.g., see the results for tidal wetlands in Tables G5-41 and G5-42, where different species drive the scaling for the impingement and entrainment losses, respectively).

An alternative presentation of the HRC valuation of the I&E losses at the Pilgrim facility is presented in Figure G5-5.

Table G5-41: Total HRC Estimates for Impingement Losses at Pilgrim

Preferred Restoration Alternative	Species Benefitting from the Restoration Alternative: Species	Species Benefitting from the Restoration Alternative: Average Annual Impingement Loss of Age 1 Equivalents	Required Units of Restoration Implementation[a]	Units of Measure for Preferred Restoration Alternative	Total Annualized Unit Cost	Total Annualized Cost
Restore SAV	Northern pipefish	118	**47**	100 m² of directly revegetated substrate	$1,233.50	$57,975
	Threespine stickleback	118	6			
	Atlantic cod	301	Unknown			
	Pollack	33	Unknown			
Restore tidal wetland	Atlantic silverside	20,842	**112,163**	m² of restored tidal wetland	$1.95	$219,092
	Winter flounder	1,144	13,000			
	Striped killifish	90	527			
	Grubby	879	Unknown			
	American sand lance	27	Unknown			
	Striped bass	9	Unknown			
	Bluefish	2	Unknown			
Create artificial reefs	Tautog	201	**6,855**	m² of reef surface area	$24.85	$170,333
	Cunner	411	70			
	Rock gunnel	77	Unknown			
	Radiated shanny	54	Unknown			
	Sculpin spp.	13	Unknown			
Install fish passageways	Alewife	4,343	**0.49**	New fish passageway	$49,437.64	$49,438[b]
	Rainbow smelt	6,885	Unknown			
	Blueback herring	703	Unknown			
	White perch	73	Unknown			
Species not valued	Blue mussel	150	Unknown for all	Restoration measures unknown — survival and reproduction may be improved by other regional objectives such as improving water quality or reducing fishing pressure if projects can be identified and are permanent improvements.	N/A	N/A
	Atlantic herring	8,836				
	Atlantic menhaden	6,165				
	Butterfish	399				
	Windowpane	284				
	Red hake	229				
	Lumpfish	217				
	Scup	114				
	Little skate	78				
	Searobin	69				
	Bay anchovy	18				
	Atlantic mackerel	3				
	Fourbeard rockling	2				
	Hogchoker	2				
	American plaice	0				
Total annualized HRC valuation						$496,878

[a] Numbers of units used to calculate costs for each restoration alternative are shown in bold.

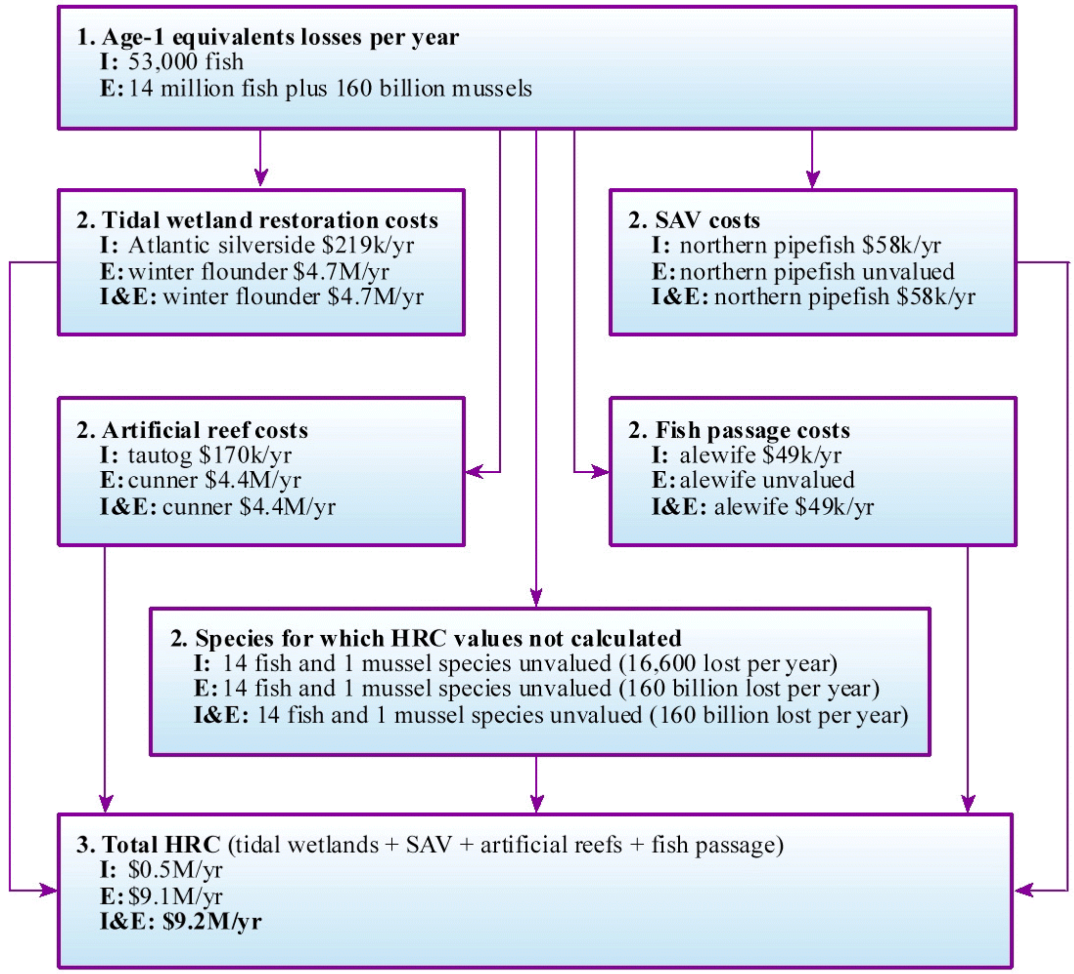
[b] Anadromous fish passageways must be implemented in whole units, and increased production data are lacking for most affected anadromous species. Therefore, one new passageway was assumed to be warranted.

Table G5-42: Total HRC Estimates for Entrainment Losses at Pilgrim

Preferred Restoration Alternative	Species Benefitting from the Restoration Alternative: Species	Species Benefitting from the Restoration Alternative: Average Annual Entrainment Loss of Age 1 Equivalents	Required Units of Restoration Implementation[a]	Units of Measure for Preferred Restoration Alternative	Total Annualized Unit Cost	Total Annualized Cost
Restore SAV	Northern Pipefish	0	**0**	100 m^2 of directly revegetated substrate	$1,233.50	Unvalued
	Theespine stickleback	0	0			
	Atlantic cod	2,138	Unknown			
	Pollack	492	Unknown			
Restore tidal wetland	Winter flounder	209,571	**2,416,621**	m^2 of restored tidal wetland	$1.95	$4,720,482
	Atlantic silverside	5,087	27,376			
	Striped killifish	0	0			
	Grubby	0	0			
	Striped bass	0	0			
	Bluefish	0	0			
	American sand lance	4,116,258	Unknown			
Create artificial reefs	Cunner	993,500	**176,145**	m^2 of reef surface area	$24.85	$4,377,887
	Tautog	875	29,843			
	Rock gunnel	4,892,795	Unknown			
	Radiated shanny	1,644,402	Unknown			
	Sculpin spp.	734,760	Unknown			
Install fish passageways	Alewife	0	**0**	New fish passageway	$49,437.64	Unvalued
	Rainbow smelt	1,323,137	Unknown			
	Blueback herring	0	Unknown			
	White perch	0	Unknown			
Species not valued	Blue mussel	159,000,000,000	Unknown for all	Restoration measures unknown - survival and reproduction may be improved by other regional objectives such as improving water quality or reducing fishing pressure if projects can be identified and are permanent improvements.	N/A	N/A
	Fourbeard rockling	411,189				
	Atlantic herring	20,243				
	Windowpane	17,258				
	Atlantic menhaden	8,105				
	Atlantic mackerel	6,659				
	Searobin	3,698				
	Red hake	1,545				
	Lumpfish	1,080				
	American plaice	221				
	Butterfish	0				
	Scup	0				
	Little skate	0				
	Bay anchovy	0				
	Hogchoker	0				
Total annualized HRC valuation						$9,098,369

[a] Numbers of units used to calculate costs for each restoration alternative are shown in bold.

Figure G5-5: I&E Overview: Pilgrim Habitat-Based Replacement Costs (annualized cost results)



G5-9 Conclusions

HRC analyses indicate that the cost of replacing organisms lost to I&E at the Pilgrim CWIS through habitat replacement is at least $9.2 million in terms of annualized costs. This value is significantly greater than the maximum annual value of $0.7 million for Pilgrim calculated by summing the maximum annual values for the various components from the commercial and recreational loss method. Recreational and commercial fishing values are lower primarily because they include only a small subset of species, life stages, and human use services that can be linked to fishing. In contrast, the HRC valuation is capable of valuing many more and, in some cases, all species and life stages, and inherently addresses all of the ecological and public services derived from organisms included in the analyses, even when the services are difficult to measure or poorly understood.

Data gaps, time constraints, and budgetary constraints prevented this HRC valuation from addressing most of the aquatic organisms lost to I&E at the Pilgrim facility. In particular, annual losses of 160 billion blue mussels and 490,000 fish comprising 14 species were not included in this HRC valuation. In addition, when confronted with data gaps EPA incorporated many cost-reducing assumptions. The Agency used this approach because the purpose of this analysis is an evaluation of potential economic losses from I&E at the Pilgrim facility and not to implement the identified restoration alternatives. The Agency incorporated these cost-reducing assumptions to ensure that benefits of various regulatory options would not be over estimated. Actual implementation of this HRC analysis in terms of restoring sufficient habitat to offset I&E losses at the Pilgrim CWIS is probably greater, and possibly much greater, than the current annualized estimate of $9.2 million.