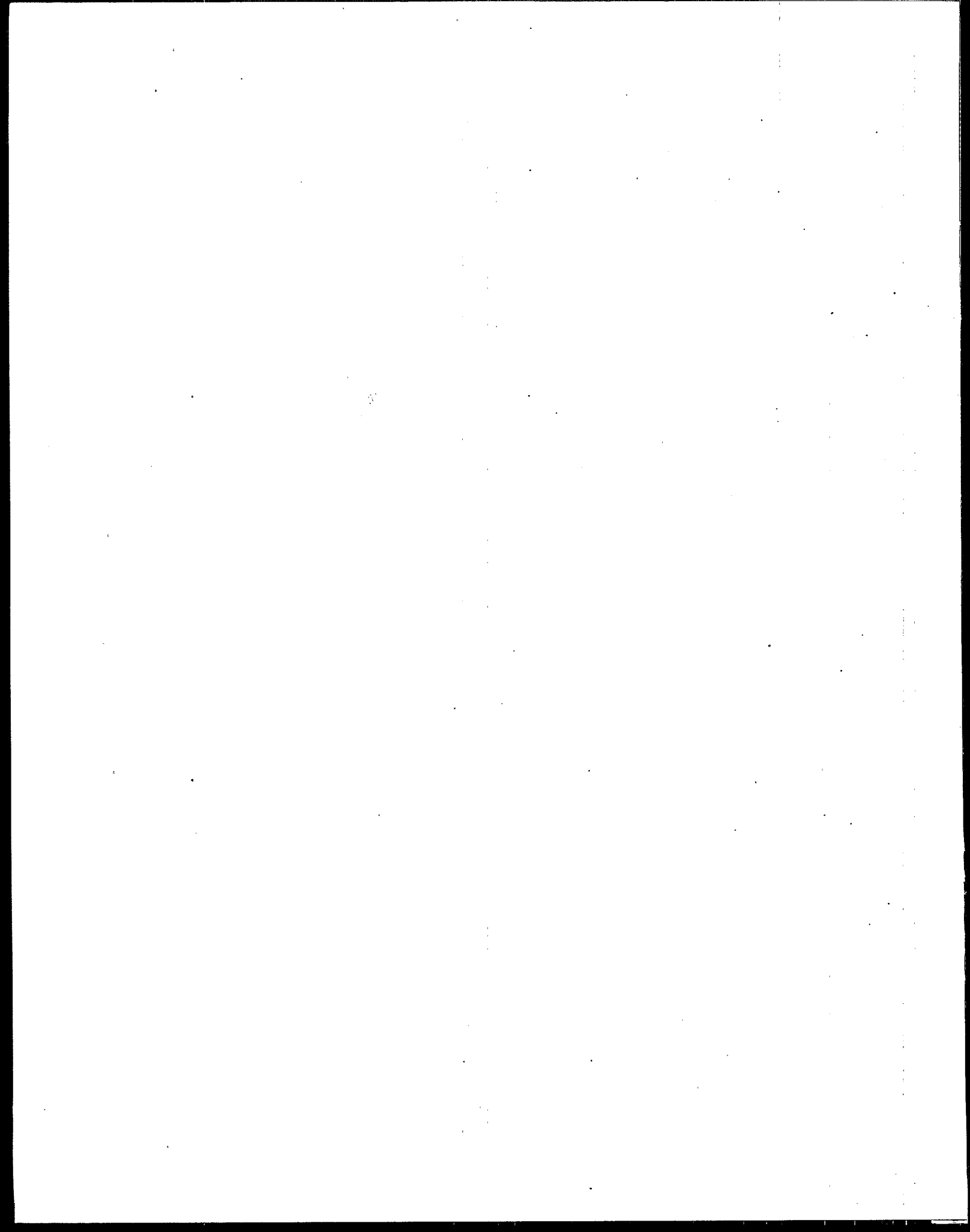**EPA**

United States
Environmental Protection
Agency

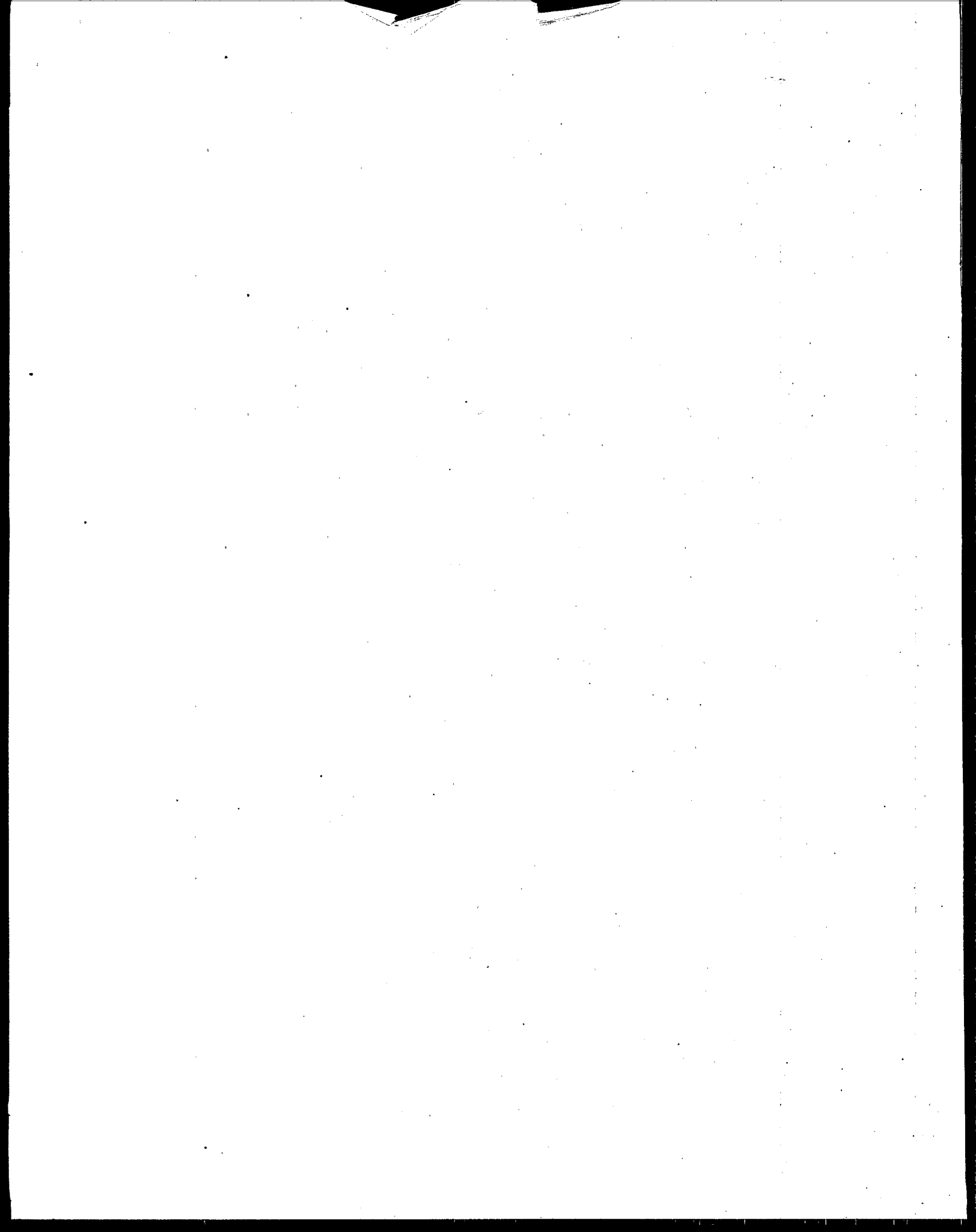# Case Study Analysis for the Proposed Section 316(b) Phase II Existing Facilities Rule
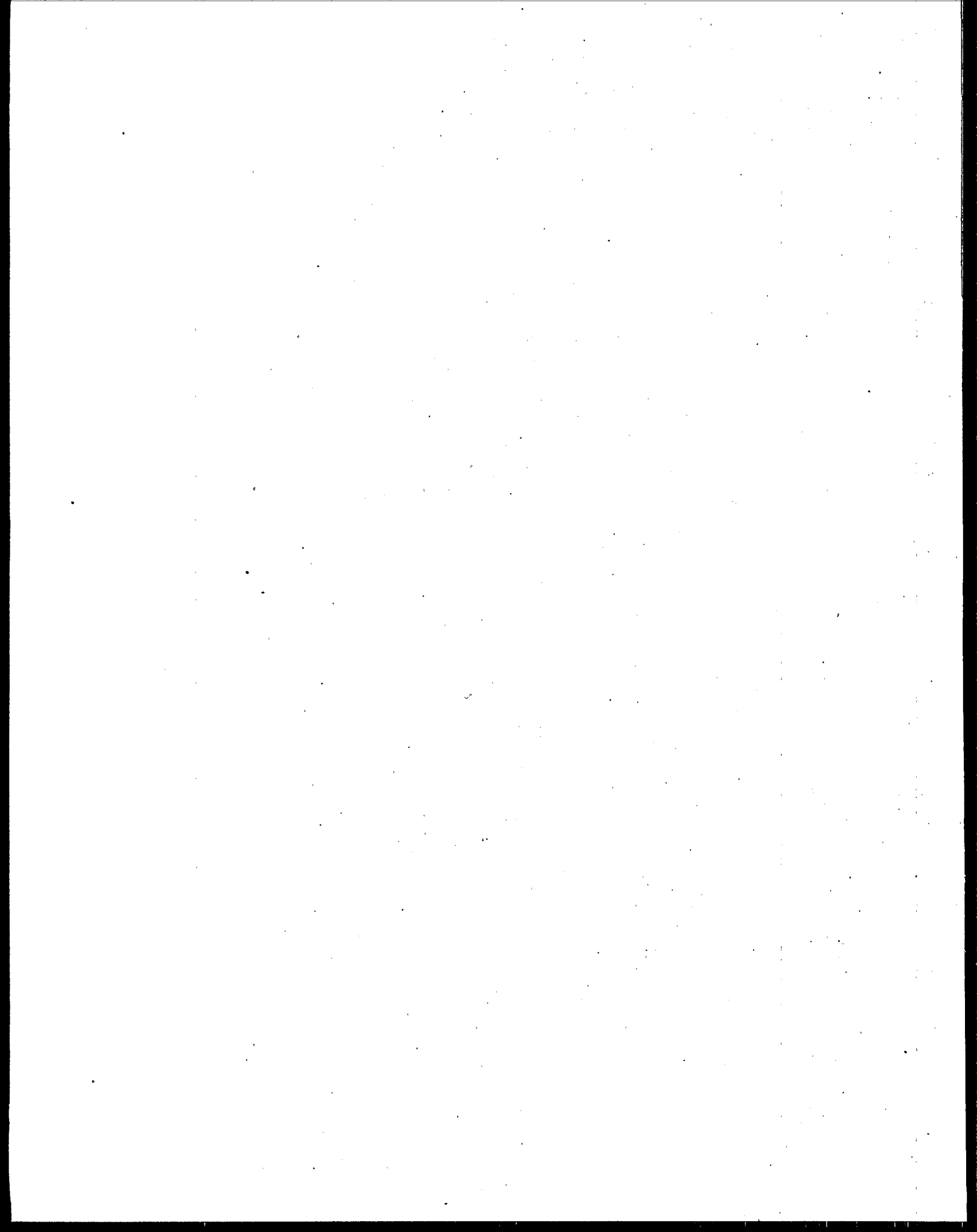
Part F - G

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U.S. Environmental Protection Agency
Office of Water (4303T)
1200 Pennsylvania Avenue, NW
Washington, DC 20460

EPA-821-R-02-002

Part F: Brayton Point Station Case Study

Chapter F1: Introduction

This report presents the results of an evaluation by EPA to assess the potential benefits of reducing the impacts of impingement and entrainment (I&E) at cooling water intake structures (CWIS) at the Brayton Point Station located on Mount Hope Bay in the Town of Somerset, Massachusetts across the mouth of the Tauton River from the city of Fall River. Mount Hope Bay in an upper embayment of Narragansett Bay. It is an interstate water comprising waters of both Massachusetts and Rhode Island.

With a capacity of 1,611 megawatts, Brayton Point Station is the largest fossil fuel burning steam-electric generating facility in New England. The station uses a once-through-cooling water system and is allowed by its current NPDES permit to withdraw up to 1.452 billion gallons a day (BGD) of cooling water from Mount Hope Bay and then discharge the heated water back into the Bay at temperatures up to 22 °F above ambient water conditions. The current National Pollution Discharge Elimination System (NPDES) permit expired in June 1998, and EPA Region 1 is currently developing conditions for a new NPDES permit. EPA co-issues this permit with the Massachusetts Department of Environmental Protection. EPA must also coordinate permit issuance closely with Rhode Island because its waters are also affected by the plant and the permit must ensure that both Massachusetts and Rhode Island water quality standards are satisfied.

Similarly, both states' Coastal Zone Management Programs must be satisfied, along with the federal Essential Fish Habitat program and other federal requirements. Other significant environmental issues at Brayton Point Station include development of plans to attain compliance with the tough, new state air regulations, possible assessment of compliance with Clean Air Act new source review requirements, on-site coal ash management, and concerns in neighboring Freetown where coal ash from the plant has been landfilled and allegedly contaminated groundwater.

There has been a significant amount of controversy about the plant because of the documented collapse of fish populations in Mount Hope Bay, an interstate water straddling the Massachusetts/Rhode Island state line, and the debate over the power plant's role in causing or contributing to the fishery decline. On October 9, 1996, Rhode Island Department of Environmental Management (RI DEM) issued a report which documented an alarming, sharp decline in abundance of finfish populations in Mount Hope Bay that appeared to occur about seventeen years ago with no subsequent recovery in evidence. Additional review of the data has suggested that the fishery decline actually began, albeit at a gentler pace, before the sharp decline evidenced around 1985. Adverse effects of plant cooling system operations on aquatic organisms can be divided into the following major categories: a) cooling water intake *entrainment* of fish eggs and larvae and other small organisms into the plant's cooling system; b) cooling water intake *impingement* of larger organisms on the intake screening systems; and c) discharge-related effects from the impacts of the thermal effluent on the aquatic community and its habitat. Entrainment and thermal discharge appear to be especially significant issues for this plant, with impingement appearing to be a relatively less major problem.

Figure F1-1 by RIDEM shows annual changes in the aggregate catch per tow for 21 fish species in Mount Hope Bay in relation to changes in total Brayton Point intake flow for 1977 through 1995 (Gibson, 1996). Analysis of these data indicated a statistically significant decreasing trend over time in Mount Hope Bay fish abundances ($p < 0.01$), with the decline averaging 16 percent per year (Gibson, 1996). Moreover, declines in 4 of the species analyzed by RIDFW (winter flounder (*Pleuronectes americanus*), windowpane (*Scophthalmus aquosus*), tautog (*Tautoga onitis*), and hogchoker (*Trinectes maculatus*)) were significantly greater in Mount Hope Bay than in the rest of Narragansett Bay.

Figure F1-1: Time Series of Annual Mean Coolant Flow at Brayton Point Station and Aggregate Fish Abundance (21 species) in Mount Hope Bay

P./Intake/Brayton/Brayton_Science/Models/sp2000/ckd.dataset.and.codes/fish.abund.flow.
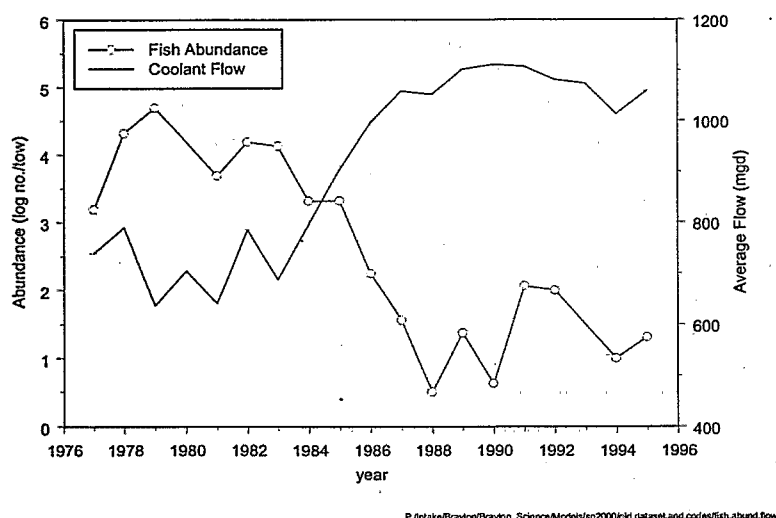
Sources: Gibson, 1996; personal communication, Meredith Simas, Environmental Engineer, Brayton Point Station, March 23, 2001.

A more recent analysis by the RIDEM (Gibson, 2001) attempted to control for other regional stressors that may be contributing to winter flounder declines, including overfishing, increased winter water temperatures, and increased predation on larvae by the shrimp *Crangon septemspinosa* (Keller and Klein-MacPhee, 2000). The analysis compared the results of winter flounder trawl surveys near and away from the plant, and confirmed that winter flounder declines near Brayton Point are not apparent in other parts of Narragansett Bay. Although winter flounder stocks in other parts of the region have increased, stocks in Mount Hope Bay have not recovered in response to a fishing ban established in 1991, suggesting that fishing pressure alone did not cause the severe population decline in Mount Hope Bay.

To evaluate the potential benefits of the proposed rule, EPA estimated expected I&E at Brayton Point under current operations based on an analysis of I&E rates before the accelerated fish population declines that followed the 1984 conversion of unit 4, as discussed in Chapter F3. It should be noted that using the pre-1984 data still probably produces an underestimate of I&E levels because some data suggests that the plant contributed to a declining fishery before 1984, though the decline accelerated precipitously after 1984. Unfortunately there is no Mount Hope Bay abundance data from before Brayton Point Station began operations to provide a true baseline unaffected by the plant. Section F1-1 of this background chapter provides a brief description of the facility, Section F1-2 describes the facility's environmental setting, and Section F1-3 presents information on the area's socioeconomic characteristics.

F1-1 OVERVIEW OF CASE STUDY FACILITY

The Brayton Point Station is located on approximately 100 ha (250 acres) of the Brayton Point peninsula in Mount Hope Bay, at the confluence of the Lee and Taunton rivers (Figure F1-2). The facility lies within the Town of Somerset, and the city of Fall River is located across the Taunton River to the southeast of the facility. The city of Swansea is located across the Lee River to the north of the facility. The Massachusetts-Rhode Island state line runs diagonally across Mount Hope Bay, which is an upper embayment of the Narragansett Bay Estuary.

Figure F1-2: Location of Brayton Point Station in Mount Hope Bay
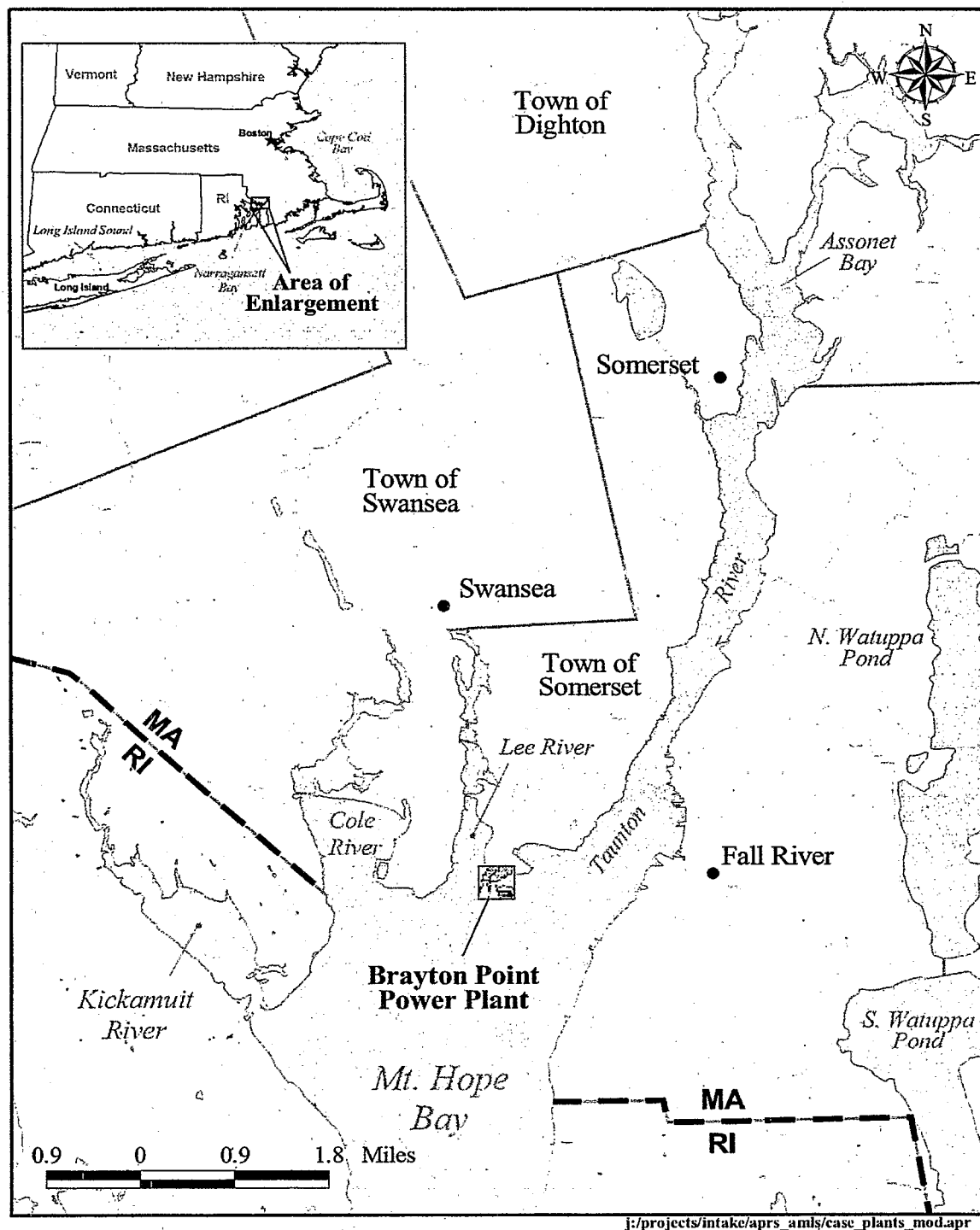
The Brayton Point power plant is in the Northeast Power Coordinating Council (NPCC). The plant began commercial service in 1963 and is operated as a baseload facility. Brayton Point operates eight units: three coal-fired steam-electric generators, one oil-fired steam-electric generator, and four internal combustion units. In 1998, Brayton Point generated 8.1 million MWh of electricity. Estimated 1998 revenues for the Brayton Point plant were $552 million, based on the plant's 1998 estimated electricity sales of 7.7 million MWh and the 1998 company-level electricity revenues of $71.38 per MWh. Brayton Point's 1998 production expenses totaled $211 million, or 2.602 cents per kWh, for an operating income of $341 million.[1]

Table F1-1 summarizes the plant characteristics of Brayton Point.

Table F1-1: Summary of Brayton Point Plant Characteristics (1998)	
Plant EIA Code	1619
NERC Region	NPCC
Total Capacity (MW)	1,611
Primary Fuel	Coal
Number of Employees	320[a]
Net Generation (million MWh)	8.1
Estimated Revenues (million)	$552
Total Production Expense (million)	$211
Production Expense (¢/kWh)	2.602¢
Estimated Operating Income (million)	$341

Notes: NERC = North American Electric Reliability Council
        NPCC = Northeast Power Coordinating Council
        Dollars are in $2001.
[a] 1995 data.
Source: U.S. Department of Energy (2001c, 2001e, 2001f).

In response to the developing controversy, federal and state regulatory agencies and former plant owner NEPCO entered into a Memorandum of Agreement (MOA) in April, 1997, regarding plant operations. The MOA places annual and seasonal caps on the level of heat discharged and the amount of cooling water withdrawn from the Bay. In the MOA the Company agreed to limit its operations to levels below that authorized by the (still) current NPDES permit and the agencies agreed not to push for an immediate modification of the permit. (NEPCO had threatened to appeal any immediate permit modification anyway.) The intake volume and thermal discharge caps in the MOA represented a compromise between the levels initially sought by the regulatory agencies and the levels the company claimed were justified. The MOA also indicated that a number of types of research should be pursued to help with development of a new NPDES permit. When PG&E bought Brayton Point Station it assumed responsibility for complying with the MOA (the MOA required that agreement to comply with the MOA be made a condition of any sale of the plant). Since the 1997 MOA, the permittee and the regulatory agencies have been engaged in extensive monitoring, modeling and study to determine the conditions for a new NPDES permit.

On October 2, 2002, PG&E publicly announced a proposed $250,000,000 environmental improvement plan for the facility including new air pollution controls, ash recycling facilities, and a new cooling water system using mechanical draft wet cooling tower that PG&E refers to as the Enhanced Multi-Mode System. The Company intends this plan to address requirements under the new State air quality regulations, a State Administrative Consent Order addressing ash management practices, and the new NPDES permit. PG&E states that this new system will reduce heat loadings into Mount Hope Bay, and reduce cooling water withdrawals from Mount Hope Bay, to pre-1984 levels. The year 1984 is significant because it was the year that Brayton Point was permitted to switch Unit 4 from a previously closed-cycle cooling system to a once-through cooling system, and some data suggests that the steep decline in fish populations was coincidental with this modification. (As noted above, there is also data suggesting that the decline had started earlier but accelerated after Unit 4 began once-through cooling operations.)

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[1] The generation, revenue, electricity sales, production expense, and operating income numbers in this section are based on FERC Form 1 data for the eight months during which the plant was operated as a regulated utility plant. EPA adjusted these values to represent the entire year using a scaling factor of 1.46 (equal to total 1998 generation divided by 8-month generation, or 8.12 million MWh/5.56 million MWh; total generation is based on U.S. Department of Energy, 2001b, 2001d).

EPA is working closely with Massachusetts and Rhode Island on the permit, and has also been coordinating with the National Marine Fisheries Service. The permit will be jointly issued with the state in Massachusetts which does not have NPDES delegation. EPA is also in close communication with the company regarding the issues and the company has submitted a substantial of information supporting its view of what limits should be in the new permit. EPA has also received significant communications from interested environmental groups. In addition, there has been congressional interest in both Massachusetts and Rhode Island as well as statements of concern by the Governor of Rhode Island. Public interest in the permit development is high. Over the past year serious concerns have been raised by groups including Save the Bay, Conservation Law Foundation, the Rhode Island Salt Water Anglers, and the New England Fishery Management Council. Also, the Rhode Island Attorney General has also been actively engaged in tracking the matter and has publicly threatened to sue the company over damage to Rhode Island's natural resources. Finally, the permit issues have received substantial attention in local major media outlets, including a recent front page story in the <u>Boston Globe</u>.

❖ *Ownership information*

Brayton Point began operation as a regulated utility plant and is currently owned by USGen New England Inc., an affiliate of PG&E National Energy Group. Brayton Point was purchased by PG&E Generating Co. from the New England Power Company (NEPCO) in 1998. Brayton Point is currently operated as a merchant generating plant, selling electricity in the deregulated wholesale generation market (Standard & Poor's, 2001b).

PG&E Corporation is one of the largest utility holding companies in the United States, with ownership of or control over approximately 18,000 MW of electric generating capacity and electricity sales of over 80 million MWh in 2000. PG&E Corporation had 20,850 employees and sales of over $26 billion in 2000. However, PG&E Corporation suffered substantial financial losses as a result of the California energy crisis, when its regulated operations subsidiary, Pacific Gas and Electric Company, which serves several million electric and gas customers in Central and Northern California, was unable to pass rising wholesale power prices on to retail consumers. As a result, Pacific Gas and Electric Company, as a subsidiary only but not as PG&E Corporation, filed for Chapter 11 bankruptcy protection in April 2001 (Hoover's Online, 2001h; PG&E, 2001; Standard & Poor's, 2001b).

F1-2 ENVIRONMENTAL SETTING

F1-2.1 Mount Hope Bay

Mount Hope Bay is an upper embayment in the northeast portion of the Narragansett Bay Estuary, which was designated as an "Estuary of National Significance" by the U.S. Congress in 1987 (NBC, 2001) (Figure 2-1). It is about 10 km (6 miles long), covering 40 km² (15.6 square miles) (NBC, 2001). The bottom of the bay is predominantly sandy, and depths average approximately 5.5 m (18 ft) at mean low water. The state line between Massachusetts and Rhode Island runs from southeast to northwest across the bay, such that the lower portion falls in Rhode Island.

Circulation of water in the bay is dominated by tidal flow, with average tidal amplitude of 1.3 m (4.4 ft) (NBC, 2001). The Narragansett Bay estuary has free connection with the open sea, and within it, freshwater from land drainage dilutes sea water.

F1-2.2 Aquatic Habitat and Biota

The Narragansett Bay Estuary consists of a variety of habitats. Salt marshes, seagrass beds, oyster beds, cobble bottoms, soft bottoms, tidal flats, beaches, rocky shores, and the open water are all essential elements of the bay ecosystem (NBEP, 1998). Of particular importance is eelgrass habitat. Eelgrass is a rooted plant that grows densely in shallow coastal waters, in what are called "eelgrass meadows." It provides food, shelter, and spawning habitat for an abundance of marine life, including economically important finfish and shellfish species such as winter flounder, tautog , bluefish (*Pomatomus saltator*), American oyster (*Crassostrea virginica*), northern quahogs or hard clams (*Mercenaria mercenaria)*, bay scallops (*Argopecten irradians*), soft-shelled clams (*Argopecten irradians*), American lobster (*Homarus americanus*), and blue crab (*Callinectes sapidus* Rathbun) (NBEP, 1998; DeAlteris et al., 2000).

The fish community of Mount Hope Bay is estuarine with coastal migrant fishes. Vast numbers of fish migrate in and out of Mount Hope Bay in seasonal patterns (NBC, 2001). Approximately 60 species of adult fishes have been identified in the bay. Truly local species include silverside (*Menidia menidia*), northern pipefish (*Syngnathus fuscus*), fourbeard rockling (*Enchelyopus cimbrius*), and seaboard goby (*Gobiosoma ginsburgi*). Local migrants, which move freely within Narragansett Bay and probably into the adjacent sounds, are winter flounder, windowpane (*Scophthalmus aquosus*), tautog, and searobin (*Triglidae*). Truly migratory species include Atlantic menhaden (*Brevoortia tyrannus*), weakfish (*Cynoscion regalis*), butterfish (*Peprilus triacanthus*), scup (*Stenotomus chrysops*), and bay anchovy (*Anchoa mitchilli*). Many of the prominent

Narragansett fish species, including striped bass (*Morone saxatilis*), bluefish, tautog, winter flounder, summer flounder/fluke (*Paralichthys dentatus*), scup and weakfish, are highly sought after by both commercial and recreational fishermen (NBEP, 1998).

Narragansett Bay is also home to waterfowl and wading birds. Over 350 species of birds have been spotted in the bay's environs (NBC, 2001). Species such as mergansers *(Mergus meraganser)*, buffleheads (*Bucephala albeola*), and great blue herons (Ardea herodias) can be found in the bay during various seasons (NBEP, 1998).

Benthic organisms that inhabit the bay include clams, quahogs, crabs, lobsters, snails, shrimps, and sponges. The dominant intertidal organisms in the rocky surfaces include the blue mussel, snail, and barnacles. Soft bottom communities are composed primarily of bivalves, amphipods, and polychaete worms (NBC, 2001).

Endangered species that live or feed in Narragansett Bay include diamond-back terrapin (*Malaclemys terrapin*), roseate tern (*Sterna dougallii*), and Kemp's ridley turtle *(Lepidochelys kempii)* (NBEP, 1998).

F1-2.3 Major Environmental Stressors

a. Habitat alteration

Water pollution, dredging, coastal development, and other environmental stressors have nearly eliminated eelgrass in Mount Hope Bay (NBEP, 1998). Though upper Narragansett Bay once supported extensive seagrass beds, they are now present only in the southern half of the bay. The vitality of an estuary's eelgrass beds is widely recognized as an indicator of an estuary's ecological health (Save the Bay, 2001).

The once abundant fish, shellfish, and birds that depend on eelgrass meadows have declined in number, because of habitat alteration and other stressors. Bay scallops began to decline in the 1950's and have yet to recover. Similarly, winter flounder, once one of the bay's most important catches, has declined precipitously over the past decade.

b. Overfishing

Fishery landings and stock sizes of many Narragansett Bay fish and shellfish species have changed dramatically (DeAlteris et al., 2000). The oyster harvest peaked at 6.8 million kg (15 million lb) in 1910, and then declined to less than 4,000 kg (10,000 lb) from 1955 to 1996. Landings of the northern quahog peaked at 2.3 million kg (5 million lb) in 1955 and then declined to less than 0.5 million kg (1 million lb) in 1998. In contrast, lobster landings have steadily increased from less than 0.05 million kg (0.1 million lb) in the early 1950's to more than 3.4 million kg (7.5 million lb) in the early 1990's. Winter flounder landings steadily increased from less than 0.2 million kg (0.5 million lb) in the 1940's to over 4 million kg (9 million lb) in the early 1980's, but then declined to about 0.5 million kg (1 million lb) in the late 1990's. Striped bass landings have fluctuated widely in the last 50 years; the fishery collapsed in the late 1970's, and then increased to almost 0.5 million kg (1 million lb) in the mid-1990's (DeAlteris et al., 2000).

c. Pollution

Narragansett Bay is one of the most densely populated estuarine systems in the country (Caton, 2001). As a result, the bay must assimilate high levels of industrially derived toxic pollutants, nutrients, and wastewater runoff from the area's 33 wastewater treatment facilities (WWTF).

In addition, large amounts of heat are discharged into Mount Hope Bay by Brayton Point and into the Taunton River, albeit at lesser amounts, by facilities such as Taunton Municipal and Montaup Station.

Based on 1990 census figures, it is estimated that 0.5 million m^3 (125 million gallons) of wastewater are either directly or indirectly discharged into Narragansett Bay each day (Caton, 2001). The greatest pollution levels can be found at the head of the bay where the metropolitan areas of Providence, Worcester, and Fall River dispose of their wastewater. Excessive levels of human waste have a number of effects on aquatic life and the recreational and commercial uses of Narragansett Bay. Of primary concern are the low levels of dissolved oxygen caused by large nutrient loadings from the WWTFs. Nitrogen discharged by facilities causes excess plant growth (algal blooms). When the algae die, they are decomposed by bacteria that consume dissolved oxygen, effectively suffocating fish and other wildlife. Similarly, bacterial nitrification of ammonia discharged by WWTFs also depletes the bay's waters of dissolved oxygen, making many waters uninhabitable (Caton, 2001).

Human sewage is also responsible for temporary and permanent closures of over 31 percent of Narragansett Bay to shellfish harvesting (Caton, 2001). Portions of Mount Hope Bay have been permanently closed to shellfish harvesting since the

1940's, and other portions are routinely closed after heavy rains cause overflow of sewage waters. Fall River is presently working on a multi-million dollar combined sewer outflow abatement program, having already made improvements to its WWTF.

Narragansett Bay also suffers from industrial toxic pollutants (Caton, 2001). Traces of industrial metals (copper, zinc, iron, mercury) and organic compounds (PCBs, PHCs, pesticides) are found in bay sediments, creating potential health risks primarily through the consumption of contaminated seafood. However, the discharge of these pollutants into the bay has decreased dramatically because of the pretreatment of industrial wastewater (NBEP, 1998).

d. Climate change

Winter water temperatures in Narragansett Bay have increased markedly over the past 40 years. Likely causes include global warming (Keller and Klein-MacPhee, 2000) and the discharge of waste heat into the bay by Brayton Point Station. This has resulted in a loss of the usual winter-spring diatom bloom, with potential impacts on higher trophic levels because of changes in prey availability (Keller et al., 1999). Warmer water in winter may also increase predation rates by the shrimp *Crangon septemspinosa* on larval winter flounder, contributing to recent population declines (Keller and Klein-MacPhee, 2000).

e. Surface water withdrawals by CWIS

Steam electric power generation accounts for the single largest intake of water from the Narragansett Bay watershed, amounting to over 85 percent of all surface water withdrawals, and 100 percent of all saline water withdrawals (USGS, 1995).

F1-3 SOCIOECONOMIC CHARACTERISTICS

Bristol County has a population of 534,678 (Table F1-2; U.S. Census Bureau, 2001), of which 18,234 live in the Town of Somerset. The county has four cities (Attleboro, Fall River, New Bedford, and Taunton) and 16 towns (BCCVB, 2002).

Table F1-2: Socioeconomic Characteristics of Bristol County, Massachusetts, and the State of Massachusetts

	Bristol County	Massachusetts	Rhode Island
Population	534,678	6,349,097	1,048,319
Land area (square miles)	556	7,840	1,045
Persons per square mile	961.7	809.8	1,003.2
Median household money income (1997 model-based estimate)	$38,866	$43,015	$36,699
Persons below poverty (%, 1997 model-based estimate)	11.9%	10.7%	11.2%
Housing units	216,918	2,621,989	439,837
Home ownership rate	61.6%	61.7%	60%
Households	205,411	2,443,580	408,424
Persons per household	2.54	2.51	2.47
Households with persons under 18 years (%)	35.6%	32.9%	32.9
High school graduates, persons 25 years and over (1990 data)	213,057	3,169,566	474,612
College graduates, persons 25 years and over (1990 data)	52,143	1,078,999	140,160

Data from 2000 except where shown.
Source: U.S. Census Bureau, 2001.

F1-3.1 Major Industrial Activities

Narragansett Bay hosts a wide range of water-dependent industries, including recreation, shipbuilding, fishing, fish processing, shipping, and military. Other industries such as electronics, magazines, and auto imports also benefit from maritime access through Narragansett Bay.

The Town of Somerset is a suburban township with some small-scale resort and second home development. It has 24 km (15 miles) of waterfront, which are primarily used for recreation. The closest city, Fall River, has more industrial activities with chemical operations, electrical and food products along with the garment and textile industries. It also draws tourism with the largest factory outlet district in New England and a World War II memorial (MDHCD, 2001).

F1-3.2 Commercial Fisheries

Commercial fishing has long been a staple activity in Narragansett Bay. In 1999, the total value of Rhode Island's commercial landings of fish and shellfish was approximately $79 million (RIEDC, 2000), and the total value of Massachusetts' commercial landings was about $260.5 million (NMFS, 2001a). It is estimated that Narragansett Bay accounts for 25-75 percent of Rhode Island's shellfish landings, 5 percent of finfish landings, and 10-25 percent of lobster landings (DeAlteris et al., 2000). The upper bay, near Brayton Point, is a major fishing area for quahogs. Narragansett Bay produces about 8 million pounds of quahogs annually, with a landed value of $6 million (NBC, 2001).

The Narragansett Bay commercial fishing industry supports a number of other fishing-related industries, including fish processing and the manufacture of commercial fishing equipment (NBC, 2001).

F1-3.3 Recreation

Narragansett Bay's most important economic activities are tourism and recreation. Outdoor recreation, including fishing, generates an estimated $2 billion in revenues each year (NBEP, 2001).

a. Recreational fishing
More than 100,000 people fish on Narragansett Bay each year. Over 32,000 recreational boats are registered on the bay, and many more are trailered from out of state. The bay's recreational fishery is valued at more than $300 million per year (NBEP, 2001).

b. Other water-based recreation
Narragansett Bay supports a great deal of other water-based recreation as well (RIEDC, 1999). Pleasure boating is especially popular, and many races and regattas are held in the summer season. Rhode Island has over 85 marinas, 28 yacht clubs, approximately 100 public boat launching sites, and over 50 charter and pleasure boats. There are also over 100 swimming beaches, and camping, picnicking, surfing, and diving are popular activities.

Chapter F2: Technical Description of the Brayton Point Station

This chapter presents technical information related to the Brayton Point facility. Section F2-1 presents an operational profile of the facility and includes Energy Information Administration (EIA) data on its generating units. Section F2-2 describes the configuration of the intake structures and water withdrawals.

F2-1 OPERATIONAL PROFILE

During 1999, the Brayton Point power plant operated eight active units.[1] Units 1-3 are coal-fired steam-electric generators; Unit 4 is an oil-fired steam-electric generator. Units 1-3 use cooling water withdrawn from the Taunton River; unit 4 uses water withdrawn from the Lee's River. The remaining four units are internal combustion turbines that do not require cooling water. All units became operational between August 1963 and December 1974.

Brayton Point's total net generation in 1999 was 8.7 million MWh. Unit 3 accounted for 4.4 million MWh, or 51 percent, of this total. Unit 1 and Unit 2 accounted for 1.8 million MWh (21 percent) and 1.7 million MWh (20 percent), respectively. The capacity utilization of Brayton Point's units ranged from 78 percent (Unit 3) to 86 percent (Unit 1). Unit 4 was on standby in 1999 and had a capacity utilization of only 18 percent.

Table F2-1 presents details for Brayton Point's eight units.

Table F2-1: Brayton Point Generator Characteristics (1999)								
Generator ID	Capacity (MW)	Prime Mover[a]	Energy Source[b]	In-Service Date	Operating Status	Net Generation (MWh)	Capacity Utilization[c]	ID of Associated CWIS
1	241	ST	BIT	Aug. 1963	Operating	1,812,283	85.8%	1
2	241	ST	BIT	Jul. 1964	Operating	1,746,259	82.7%	2
3	643	ST	BIT	Jul. 1969	Operating	4,400,369	78.2%	3
4	476	ST	FO6	Dec. 1974	Standby	744,188	17.9%	4
IC1	2.8	IC	FO2	Mar. 1967	Cold Standby	204	0.8%	Not applicable
IC2	2.8	IC	FO2	Mar. 1967	Cold Standby	176	0.7%	
IC3	2.8	IC	FO2	Mar. 1967	Cold Standby	181	0.8%	
IC4	2.8	IC	FO2	Mar. 1967	Cold Standby	188	0.8%	
Total	1,611					8,703,848	61.7%	

[a] Prime mover categories: ST = steam turbine; IC = internal combustion.
[b] Energy source categories: Oil; BIT = bituminous coal; FO6 = No. 6 Fuel Oil; FO2 = No. 2 Fuel.
[c] For this analysis, capacity utilization was calculated by dividing the unit's actual net generation by the potential generation if the unit ran at full capacity all the time (i.e., capacity * 24 hours * 365 days).
Source: U.S. Department of Energy, 2001a and 2001c.

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[1] For the purposes of this analysis, "active" units include generating units that are operating, on standby, on cold standby, on test, on maintenance/repairs, or out of service (all year). Active units do not include units that are on indefinite shutdown or retired.

F2-2 CWIS CONFIGURATION AND WATER WITHDRAWAL

Brayton Point operates two distinct cooling water systems to serve its four generating units. Cooling Water System #1 (CWS #1) serves generating units 1-3 while Cooling Water System #2 (CWS #2) provides cooling water for the fourth generating unit. The operation of these two systems over time is summarized in Table F2-2 and discussed below.

Table F2-2: Brayton Point Timeline of CWIS Operations

Time Period	CWIS #1	CWIS #2
1963-1969	Units 1,2,3 put into operation. All three served by the same intake structure with the following configuration: ▸ Source water: Taunton River ▸ Six intake bays (2 for each unit) ▸ Conventional once-through system ▸ Trash rack ▸ Conventional traveling screen (rotated every 8 hours) ▸ High pressure spray wash (120 psi) to remove debris and fish ▸ Sluiceway to carry debris and fish to discharge point beyond the influence of the intake structure ▸ Design intake flow: 925 MGD *Seasonal Variation:* May to October of each year fixed screens are placed on the trash racks to prevent impingement of horseshoe crabs on the traveling screen. Fixed screens are hauled and washed as necessary.	N/A
1969-1973	Operations unchanged from above.	N/A
1974	Operations unchanged from above.	Unit 4 put into operation. Served by one intake structure with the following configuration: ▸ Source Water: Lee River ▸ One intake bay ▸ Closed-cycle cooling system ▸ Trash racks ▸ Conventional traveling screen (uncertain about rotation/cleaning schedule, but unlikely continuous)
1975-1981	Operations unchanged from above.	Operations unchanged from above.
1981	Operations unchanged from above.	Unit 4 begins piggyback operation. Water intake from Lee River ceases. All cooling water taken from discharges from CWIS #1
1982	Operations unchanged from above.	Piggyback operation.
1983	Unit 3 shut down for seven months. (8/83-2/84)	Piggyback operation.

Table F2-2: Brayton Point Timeline of CWIS Operations 1969-Present (cont.)

Time Period	CWIS #1	CWIS #2
1984	All units operational. No change from configuration above.	Unit 4 begins once-through cooling (7/15/84) with the following configuration: ▸ Source water: Lee River ▸ One intake bay ▸ Trash racks ▸ Angled traveling screens. Six traveling screens set 25° from upstream flow. ▸ Fish bypass intakes at the apex of angled screens. ▸ Fish baskets (with water retention) mounted to screens. ▸ Low-pressure spray to remove impinged fish. ▸ High-pressure spray to remove debris. ▸ Separate fish and debris troughs. ▸ Screens rotate at various speeds depending on water differential. ▸ Design intake flow: 395 MGD
1985	Unit 3 shut down for seven months. (8/85-2/86).	Fine mesh screens added to traveling screen structure from 3/85-9/85. All other operations remain unchanged.
1986-1993	Unit 3 shut down for six months (8/86-1/87).	Operates at original once-through configuration.
1993	Operates at original configuration.	Piggyback for one month (2/25/93-3/31/93).
1994	Operates at original configuration.	Piggyback operation for two months (2/18/94-4/29/94).
1995	Unit 3 shut down for 2 months (2/18/-4/30). Facility notes this is a "piggyback equivalent."	Operates at original once-through configuration.
1996	Operates at original configuration.	Piggyback operation for two months (2/27-4/30).
1997	MOA II instituted. Traveling screens begin continuous operation on CWIS #1. Facility-wide intake flow restricted to 925 MGD during the winter season and 1,130 MGD during the summer season. Unit 4 required to operate piggyback at least eight months of the year.	
	Traveling screens operate continuously.	Piggyback operation for eight months (2/6-3/30, 4/17-5/28, 10/2/97-5/27/98)
1998	No change from above.	Piggyback operation for eight months (10/1/98-5/30/99).
1999	No change from above.	Piggyback operation for eight months (10/9/99-5/30/00).
2000	No change from above.	Piggyback operation for eight months (9/29/00-5/3/01).

a. Cooling water system #1

First placed into service in 1963 with the commencement of operations in generating unit #1, CWS #1 consists of one cooling water intake structure to the east of the main facility that serves a conventional once-through system. A total of six intake bays (two for each generating unit) withdraw water from the Taunton River. The intake bay depth is approximately 6.1m below the mean sea level. Intake openings for bays 1-4 (serving generating units 1 and 2) are approximately 3.7m wide, while those for bays 5 and 6 are approximately 5.2m wide. Each intake bay shares the same technological configuration.

CWS #1 currently employs trash racks and a continuously-rotating traveling screen across each of its six intake bays. Neither technology is particularly effective at reducing impingement and/or entrainment losses. Cooling water withdrawn from the Taunton River first passes through the trash racks into the intake channel. Next are conventional traveling screens equipped with wire mesh panels with openings of $9.5mm^2$. The screens continuously move in a vertical direction to remove impinged organisms and debris. Impinged items are washed off the intake screen with a high-pressure spray (120 psi) within the screen assembly. All debris is deposited in a sluiceway and carried to a discharge point approximately 300ft to the east of the intake structure.

CWS #1 modifies its intake operations seasonally to account for changes in available cooling water and migratory patterns of indigenous organisms. From May to October, fixed screens are placed on the trash racks to prevent impingement of horseshoe crabs on the traveling screens. Since 1993, Brayton Point has operated under a Memorandum of Agreement (MOA II) that effectively limits the maximum intake of CWS #1 to 925 MGD.

b. Cooling water system #2

CWS #2 began conventional once-through operation in 1984 with an angled screen assembly with fish buckets and a fish diversion/return system to reduce impingement mortality. No entrainment technology is currently in place.

An 18-month study conducted by the New England Power Company at the Brayton Point Station assessed the efficacy of the angled screen/fish diversion assembly in reducing impingement losses at CWS #2 (Lawler, Matusky & Skelly Engineers, 1987). The study calculated the Diversion Efficiency (DE) of the system (the percentage of organisms that are either impinged against the screen or diverted into the fish bypass pipe; this does not include entrained organisms) to be 76.3 percent. Excluding bay anchovy from the species increased the DE to 89.7 percent.[2] The Total System Efficiency (TSE) represents the probability that a fish entering the angled screen system will be returned to the source waterbody and survive for 48 hours. The study calculated the TSE of the system to be 33.1 percent. Excluding bay anchovy from the sample species increased the TSE to 55.4 percent.[3,4]

Originally designed as a closed-cycle system and placed into service in 1974 as the source of cooling water for generating unit #4, CWS#2 currently operates as a conventional once-through system to the north of the main facility. Water is withdrawn from the Lee River. The entire intake structure is approximately 44m long with an intake opening 34m. Cooling water enters the intake through eight 3.4m-wide openings that extend from a depth of 5.5m below the mean sea level to 1.2m above the mean sea level.

Cooling water withdrawn from the Lee River first passes through trash racks that extend to the bottom of the opening at an average approach velocity of 0.5 feet per second (fps). Downstream of the trash racks are six traveling screens angled 25° from the direction of flow in the intake waterway. The screens are set perpendicular to the screenwell floor and have $9.5mm^2$ mesh panels. At the apex of the triangle formed by the angled screens are fish bypass inlets leading to two fish return pipes that carry unimpinged fish back to the Lee River. The screens rotate vertically on a continuous basis; the speed is determined by the differential in water height between the upstream and downstream sides of the screen face. Fish impinged against the traveling screens are captured in fish buckets mounted to each screen assembly. The fish buckets rotate with the screens while retaining sufficient water for any captured organisms. A low-pressure spray (5-10 psi) removes most aquatic organisms into a

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[2] Bay anchovy are the dominant fish species, in terms of number, at the Brayton Point facility. Inordinately high impingement rates for bay anchovy occurred during a six-month test period during which fine mesh screens ($1.0mm^2$) replaced the $9.5mm^2$ screens. Current operations only employ the wide mesh screens.

[3] *Ibid.*

[4] EPA does not typically use a 48-hour survival standard when determining the efficacy of an impingement technology. However, for the purposes of this case study only (Mt. Hope Bay), EPA will use the facility's determination.

separate fish trough which then carries them to the fish diversion pipe and back to the Lee River. A high-pressure spray (120 psi) washes remaining debris into a debris trough.

At maximum capacity, Brayton Point CWS #2 can withdraw 395 MGD from the Lee River. Since 1997, the facility has operated under MOA II, which limits the facility-wide intake flow during the winter months to 925 MGD. In an effort to reduce the entrainment of winter flounder during the spawning season, CWS #2 does not withdraw water from the Lee River from October through May. During this time, cooling water is obtained by diverting discharged water from CWS #1 to the intake canal for CWS #2 ("piggyback operation"). Generating units 1-3 typically discharge less heat as a result of operations, thereby making this process feasible. From 1984 (introduction of the once-through system for CWS #2) to 1997, piggyback operation was used intermittently. Table F2-3 summarizes the modes of operation of Unit 4 from 1973 through 2000.

Table F2-3: Modes of Operation of Brayton Unit 4 from 1973 to 1978

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1977	CC	CC	CC	CC	CC	CC	CC	CC	CC	CC	CC	CC
1978	CC	CC	CC	CC	CC	CC	CC	CC	CC	CC	CC	CC
1979	CC	CC	CC	CC	CC	CC	CC	CC	CC	CC	CC	CC
1980	CC	CC	CC	CC	CC	CC	CC	CC	CC	CC	CC	CC
1981	PB	PB	PB	PB	PB	PB	PB	PB	PB	PB	PB	PB
1982	PB	PB	PB	PB	PB	PB	PB	PB	PB	PB	PB	PB
1983	PB	PB	PB	PB	PB	PB	PB	PB	PB	PB	PB	PB
1984	PB	PB	PB	PB	PB	PB	OC	OC	OC	OC	OC	OC
1985	OC	OC	OC	OC	OC	OC	OC	OC	OC	OC	OC	OC
1986	OC	OC	OC	OC	OC	OC	OC	OC	OC	OC	OC	OC
1987	OC	OC	OC	OC	OC	OC	OC	OC	OC	OC	OC	OC
1988	OC	OC	OC	OC	OC	OC	OC	OC	OC	OC	OC	OC
1989	OC	OC	OC	OC	OC	OC	OC	OC	OC	OC	OC	OC
1990	OC	OC	OC	OC	OC	OC	OC	OC	OC	OC	OC	OC
1991	OC	OC	OC	OC	OC	OC	OC	OC	OC	OC	OC	OC
1992	OC	OC	OC	OC	OC	OC	OC	OC	OC	OC	OC	OC
1993	OC	OC	PB	OC	OC	OC	OC	OC	OC	OC	OC	OC
1994	OC	OC	PB	PB	OC	OC	OC	OC	OC	OC	OC	OC
1995	OC	OC	OC	OC	OC	OC	OC	OC	OC	OC	OC	OC
1996	OC	OC	PB	PB	OC	OC	OC	OC	OC	OC	OC	OC
1997	OC	PB	PB	PB	PB	OC	OC	OC	OC	PB	PB	PB
1998	PB	PB	PB	PB	PB	OC	OC	OC	OC	PB	PB	PB
1999	PB	PB	PB	PB	PB	OC	OC	OC	OC	PB	PB	PB
2000	PB	PB	PB	PB	PB	OC	OC	OC	OC	PB	PB	PB

Notes: CC = close-cycle cooling mode; OC = open-cycle mode; PB = piggyback mode.
Source: Personal communication, Meredith Simas, Environmental Engineer, Brayton Point Station, March 23, 2001.

F2-3 BRAYTON POINT GENERATION

During 1999, the Brayton Point power plant operated eight active units.[5] Total net generation in 1999 was 8.7 million MWh. Unit 3 accounted for 4.4 million MWh, or 51 percent, of this total. Unit 1 and Unit 2 accounted for 1.8 million MWh (21 percent) and 1.7 million MWh (20 percent), respectively. The capacity utilization of Brayton Point's units ranged from 78 percent (Unit 3) to 86 percent (Unit 1). Unit 4 was on standby in 1999 and had a capacity utilization of only 18 percent.

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[5] For the purposes of this analysis, "active" units include generating units that are operating, on standby, on cold standby, on test, on maintenance/repairs, or out of service (all year). Active units do not include units that are on indefinite shutdown or retired.

Table F2-4 presents details for Brayton Point's eight units.

Generator ID	Capacity (MW)	Prime Mover[a]	Energy Source[b]	In-Service Date	Operating Status	Net Generation (MWh)	Capacity Utilization[c]	ID of Associated CWIS
1	241	ST	BIT	Aug. 1963	Operating	1,812,283	85.8%	1
2	241	ST	BIT	Jul. 1964	Operating	1,746,259	82.7%	2
3	643	ST	BIT	Jul. 1969	Operating	4,400,369	78.2%	3
4	476	ST	FO6	Dec. 1974	Standby	744,188	17.9%	4
IC1	2.8	IC	FO2	Mar. 1967	Cold Standby	204	0.8%	Not applicable
IC2	2.8	IC	FO2	Mar. 1967	Cold Standby	176	0.7%	
IC3	2.8	IC	FO2	Mar. 1967	Cold Standby	181	0.8%	
IC4	2.8	IC	FO2	Mar. 1967	Cold Standby	188	0.8%	
Total	1,611					8,703,848	61.7%	

Table F2-4: Brayton Point Generator Characteristics (1999)

[a] Prime mover categories: ST = steam turbine; IC = internal combustion.
[b] Energy source categories: Oil; BIT = bituminous coal; FO6 = No. 6 Fuel Oil; FO2 = No. 2 Fuel.
[c] For this analysis, capacity utilization was calculated by dividing the unit's actual net generation by the potential generation if the unit ran at full capacity all the time (i.e., capacity * 24 hours * 365 days).
Source: U.S. Department of Energy, 2001c; U.S. Department of Energy, 2001a, for Net Generation and CWIS ID.

Figure F2-1 below presents Brayton Point's electricity generation history between 1970 and 2000.

Figure F2-1: Brayton Point Net Electricity Generation 1970 - 2000 (in MWh)
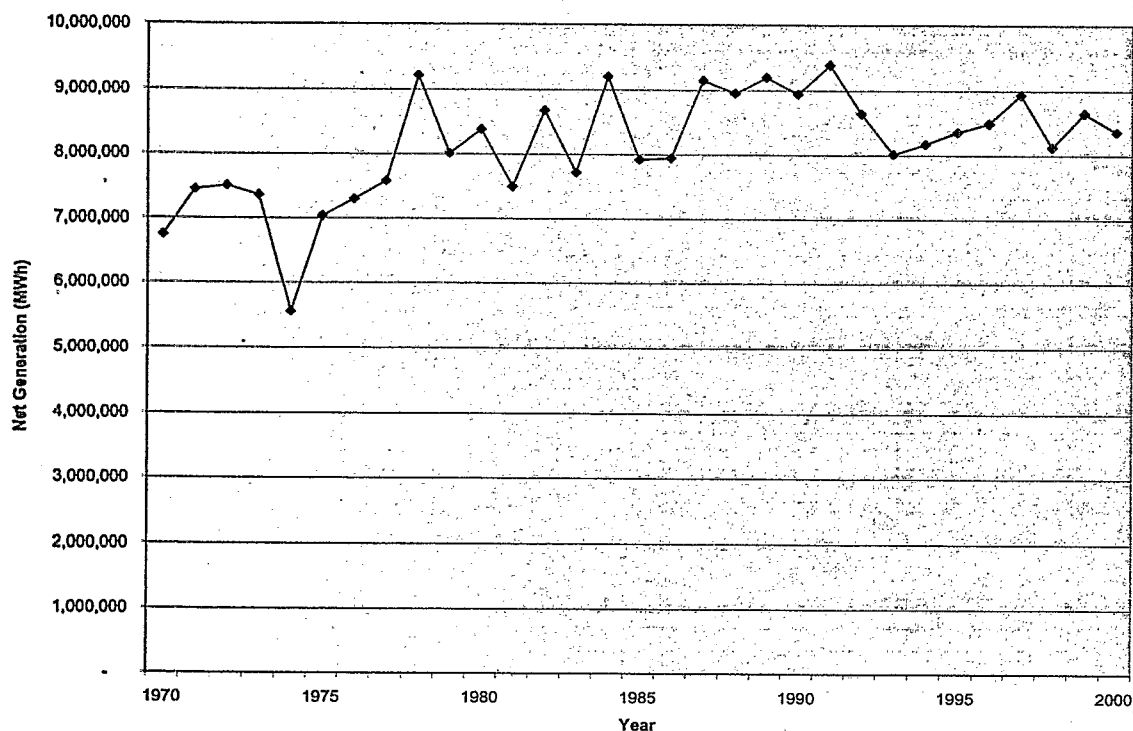
Source: U.S. Department of Energy, 2001c, 2001d.

Chapter F3:
Evaluation of I&E Data

This chapter presents the results of EPA's evaluation of potential impingement and entrainment (I&E) of aquatic organisms in Mount Hope Bay resulting from the CWIS of Brayton Point. The focus of EPA's evaluation was the potential impacts of Brayton Point's current operations on relatively healthy fish populations. Because fish populations in Mount Hope Bay are currently depressed well below historical levels, EPA based its evaluation on the most comprehensive historical time series of I&E data for Brayton Point (1974-1983) and adjusted these rates for the facility's current technologies and operations. It should be noted, however, that using pre-1984 data still probably produces an underestimate of I&E levels because there is data suggesting that the plant contributed to a declining fishery even before 1984, though the decline accelerated precipitously after 1984. Unfortunately, there is no Mount Hope Bay abundance data from before Brayton Point Station began operations to provide true baseline population levels unaffected by the plant. Section F3-1 lists fish species that are impinged and entrained at Brayton Point, and Section F3-2 presents life histories of the most abundant species in the facility's I&E collections. Section F3-3 summarizes the facility's I&E collection methods, and Section F3-4 presents results of EPA's analysis of annual impingement and entrainment. Section F3-5 summarizes the results of EPA's analyses.

F3-1 SPECIES IMPINGED AND ENTRAINED AT BRAYTON POINT

EPA evaluated species known to be impinged and entrained at Brayton Point based on information provided in facility I&E monitoring reports (PG&E Generating and Marine Research Inc., 1999; personal communication, Meredith Simas, Environmental Engineer, Brayton Point Station, January 24, 2002). Approximately 18 different species have been identified in Brayton Point's I&E collections since monitoring began in 1972. At least 10 (56 percent) of these species have commercial and/or recreational value. Table F3-1 lists species identified in the facility's I&E collections. EPA evaluated all the species impinged and entrained at Brayton Point, except a group of unidentified impinged fish species.

Table F3-1: Aquatic Species Identified in I&E Collections by Brayton Point

Common Name	Scientific Name	Commercial	Recreational	Forage
Alewife	*Alosa pseudoharengus*			X
American sand lance	*Ammodytes americanus*			X
Atlantic menhaden	*Brevoortia tyrannus*	X		
Atlantic silverside	*Menidia menidia*			X
Bay anchovy	*Anchoa mitchilli*			X
Blueback herring	*Alosa aestivalis*			X
Butterfish	*Peprilus triacanthus*	X		
Hogchoker	*Trinectes maculatus*			X
Rainbow smelt	*Osmerus mordax mordax*	X		
Scup	*Stenotomus chrysops*	X	X	
Seaboard goby	*Gobiosoma ginsburgi*			X
Silver hake	*Merluccius bilinearis*	X		
Striped killifish	*Fundulus majalis*			X
Tautog	*Tautoga onitis*	X	X	
Threespine stickleback	*Gasterosteus aculeatus aculeatus*			X
Weakfish	*Cynoscion regalis*	X	X	
White perch	*Morone americana*	X	X	
Windowpane	*Scophthalmus aquosus*	X		
Winter flounder	*Pleuronectes americanus*	X	X	

Sources: PG&E Generating and Marine Research Inc., 1999; Matt Camisa, Fisheries Supervisor, Massachusetts DMF, Personal Communication, January 31, 2002; personal communication, Meredith Simas, Environmental Engineer, Brayton Point Station, January 24, 2002.

F3-2 LIFE HISTORIES OF MAJOR SPECIES IMPINGED AND ENTRAINED

Alewife (*Alosa pseudoharengus*)

Alewife is a member of the herring family, Clupeidae, and ranges along the Atlantic coast from Newfoundland to North Carolina (Scott and Crossman, 1998). Alewife tend to be more abundant in the mid-Atlantic and along the northeastern coast. They are anadromous, migrating inland from coastal waters in the spring to spawn. Adult alewife overwinter along the northern continental shelf, settling at the bottom in depths of 56 to 110 m (184 ft to 361 ft) (Able and Fahay, 1998). Adults feed on a wide variety of food items, while juveniles feed mainly on plankton (Waterfield, 1995).

Alewife has been introduced to a number of lakes to provide forage for sportfish (Jude et al., 1987b). Ecologically, alewife is an important prey item for many fish, and commercial landings of river herring along the Atlantic coast have ranged from a high of 33,974 metric tons (74.9 million lb) in 1958 to a low of less than 2,268 metric tons (5 million lb) in recent years (Atlantic States Marine Fisheries Commission , 2000b).

Spawning is temperature-driven, beginning in the spring as water temperatures reach 13 to 15 °C (55 to 59 °F) and ending when they exceed 27 °C (80.6 °F) (Able and Fahay, 1998). Spawning takes place in the upper reaches of coastal rivers, in slow-flowing sections of slightly brackish or freshwater.

Females lay demersal eggs in shallow water less than 2 m (6.6 ft) deep (Wang and Kernehan, 1979). They may lay from 60,000 to 300,000 eggs at a time (Kocik, 2000). The demersal eggs are 0.8 to 1.27 mm (0.03 to 0.05 in.) in diameter. Larvae hatch at a size of approximately 2.5 to 5.0 mm (0.1 to 0.2 in.) total length (Able and Fahay, 1998). Larvae remain in the upstream spawning area for some time before drifting downstream to natal estuarine waters. Juveniles exhibit a diurnal vertical migration in the water column, remaining near the bottom during the day and rising to the surface at night (Fay et al., 1983a). In the fall, juveniles move offshore to nursery areas (Able and Fahay, 1998).

Maturity is reached at an age of 3 to 4 years for males, and 4 to 5 years for females (Able and Fahay, 1998). The average size at maturity is 265 to 278 mm (10.4 to 10.9 in.) for males and 284 to 308 mm (11.2 to 12.1 in.) for females (Able and Fahay, 1998). Alewife can live up to 8 years, but the average age of the spawning population tends to be 4 to 5 years (Waterfield, 1995; Public Service Electric and Gas Company, 1999c).

ALEWIFE
(Alosa pseudoharengus)

Family: Clupeidae (herrings).

Common names: River herring, sawbelly, kyak, branch herring, freshwater herring, bigeye herring, gray herring, grayback, white herring.

Similar species: Blueback herring.

Geographic range: Along the western Atlantic coast from Newfoundland to North Carolina.[a]

Habitat: Wide-ranging, tolerates fresh to saline waters, travels in schools.

Lifespan: May live up to 8 years.[b,c]

Fecundity: Females may lay from 60,000 to 300,000 eggs at a time.[d]

Food source: Small fish, zooplankton, fish eggs, amphipods, mysids.[c]

Prey for: Striped bass, weakfish, rainbow trout.

Life stage information:

Eggs: demersal
- Found in waters less than 2 m (6.6 ft) deep.[d]
- Are 0.8 to 1.27 mm (0.03 to 0.05 in.) in diameter.[f]

Larvae:
- Approximately 2.5 to 5.0 mm (0.1 to 0.2 in.) at hatching.[f]
- Remain in upstream spawning area for some time before drifting downstream to natal estuarine waters.

Juveniles:
- Stay on the bottom during the day and rise to the surface at night.[g]
- Emigrate to ocean in summer and fall.[f]

Adults: anadromous
- Reach maturity at 3-4 years for males and 4-5 years for females.[f]
- Average size at maturity is 265-278 mm (10.4-10.9 in.) for males and 284-308 mm (11.2-12.1 in.) for females.[f]
- Overwinter along the northern continental shelf.[f]

[a] Scott and Crossman, 1998.
[b] PSEG, 1999c.
[c] Waterfield, 1995.
[d] Kocik, 2000.
[e] Wang and Kernehan, 1979.
[f] Able and Fahay, 1998.
[g] Fay et al., 1983a.
Fish graphic courtesy of New York Sportfishing and Aquatic Resources Educational Program, 2001.

Atlantic menhaden (*Brevoortia tyrannus*)

The Atlantic menhaden, a member of the Clupeidae (herring) family, is a eurohaline species, occupying coastal and estuarine habitats. It is found along the Atlantic coast of North America, from Maine to northern Florida (Hall, 1995). Adults congregate in large schools in coastal areas; these schools are especially abundant in and near major estuaries and bays. They consume plankton, primarily diatoms and dinoflagellates, which they filter from the water through elaborate gill rakers. In turn, menhaden are consumed by almost all commercially and recreationally important piscivorous fish, as well as by dolphins and birds (Hall, 1995).

The menhaden fishery, one of the most important and productive fisheries on the Atlantic coast, is a multimillion-dollar enterprise (Hall, 1995). Menhaden are considered an "industrial fish" and are used to produce products such as paints, cosmetics, margarine (in Europe and Canada), and feed, as well as bait for other fisheries. Landings in New England declined to their lowest level of approximately 2.7 metric tons (5,952 lb) in the 1960s because of overfishing. Since then, landings have varied, ranging from approximately 240 metric tons (529,100 lb) in 1989 to 1,069 metric tons (2,356,742 lb) in 1998 (Personal Communication, National Marine Fisheries Service, Fisheries Statistics and Economics Division, Silver Spring, Maryland, March 19, 2001).

Atlantic menhaden spawn year round at sea and in larger bays (Scott and Scott, 1988). Spawning peaks during the southward fall migration and continues throughout the winter off the North Carolina coast. There is limited spawning during the northward migration and during summer months (Hall, 1995). The majority of spawning occurs over the inner continental shelf, with less activity in bays and estuaries (Able and Fahay, 1998).

Females mature just before age 3, and release buoyant, planktonic eggs during spawning (Hall, 1995). Atlantic menhaden annual egg production ranges from approximately 100,000 to 600,000 eggs for fish age 1 to age 5 (Dietrich, 1979). Eggs are spherical and between 1.3 to 1.9 mm (0.05 to 0.07 in.) in diameter (Scott and Scott, 1988).

Larvae hatch after approximately 24 hours and remain in the plankton. Larvae hatched in offshore waters enter the Delaware Estuary 1 to 2 months later to mature (Hall, 1995). Juveniles then migrate south in the fall, joining adults off North Carolina in January (Hall, 1995). Water temperatures below 3 °C (37 °F) kill the larvae, and therefore larvae that fail to reach estuaries before the fall are more likely to die than those arriving in early spring (Able and Fahay, 1998). Larvae hatchout at 2.4 to 4.5 mm (0.09 to 0.18 in.). The transition to the juvenile stage occurs between 30 and 38 mm (1.2 and 1.5 in.) (Able and Fahay, 1998). The juvenile growth rate in some areas is estimated to be 1 mm (0.04 in.) per day (Able and Fahay, 1998).

During the fall and early winter, most menhaden migrate south off of the North Carolina coast, where they remain until March and early April. They avoid waters below 3 °C, but can tolerate a wide range of salinities from less than 1 percent up to 33-37 percent (Hall, 1995). Sexual maturity begins at age 2, and all individuals are mature by age 3 (Scott and Scott, 1988).

Adult fish are commonly between 30 and 35 cm (11.8 and 13.8 in.) in length. The maximum age of a menhaden is approximately 7 to 8 years (Hall, 1995), although individuals of 8-10 years have been recorded (Scott and Scott, 1988).

ATLANTIC MENHADEN
(*Brevoortia tyrannus*)

Family: Clupeidae (herrings).

Common names: menhaden, bunker, fatback, bugfish.

Similar species: Gulf menhaden, yellowfin menhaden.

Geographic range: From Maine to northern Florida along the Atlantic coast.[a]

Habitat: Open-sea, marine waters. Travels in schools.[b]

Lifespan:
- Approximately 7 to 8 years.[a]

Fecundity:
- Females may produce between 100,000 to 600,000 eggs.[c]

Food Source: Phytoplankton, zooplankton, annelid worms, detritus[b]

Prey for: Sharks, cod, pollock, hakes, bluefish, tuna, swordfish, seabirds, whales, porpoises.[b]

Life stage information:

Eggs: pelagic
- Spawning takes place along the inner continental shelf, in open marine waters.[d]
- Eggs hatch after approximately 24 hours.

Larvae: pelagic
- Larvae hatch out at sea, and enter estuarine waters 1 to 2 months later.[a]
- Remain in estuaries through the summer, emigrating to ocean waters as juveniles in September or October.[d]

Adults:
- Congregate in large schools in coastal areas.
- Spawn year round.[b]

[a] Hall, 1995.
[b] Scott and Scott, 1988.
[c] Dietrich, 1979.
[d] Able and Fahay, 1998.
Fish graphic from South Carolina Department of Natural Resources, 2001.

Atlantic silverside (*Menidia menidia*)

The Atlantic silverside is a member of the silverside family, Atherinidae. Its geographic range extends from coastal waters of New Brunswick to northern Florida (Fay et al., 1983b), but it is most abundant between Cape Cod and South Carolina (Able and Fahay, 1998). Atlantic silversides inhabit sandy seashores and the mouths of inlets (Froese and Pauly, 2001). Silversides are an important species of forage fish, eaten by valuable fishery species such as striped bass (*Morone saxatilis*), bluefish (*Pomatomus salatrix*), weakfish (*Cynoscion regalis*), and Atlantic mackerel (*Scomber scombrus*) (Fay et al., 1983b; McBride, 1995).

Atlantic silversides spawn in the upper intertidal zone during spring and summer. Spawning appears to be stimulated by new and full moons, in association with spring tides. On average, females produce 4,500 to 5,000 demersal eggs per spawning season, which may include four to five separate spawning bouts (Fay et al., 1983b). The eggs are 0.9 to 1.2 mm (0.04 to 0.05 in.) in diameter. Larvae range in size from 5.5 to 15.0 mm (0.2 to 0.6 in.) (Fay et al., 1983b). The sex of Atlantic silversides is determined during the larval stage, at approximately 32 to 46 days after hatching. Water temperatures between 11 and 19 °C (52 and 66 °F) produce significantly more females, whereas temperatures between 17 and 25 °C (63 and 77 °F) produce significantly more males (Fay et al., 1983b).

Juveniles occur in estuaries during the summer months, occupying intertidal creeks, marshes, and shore zones of bays and estuaries. Silversides typically migrate offshore in the winter (McBride, 1995). In studies of seasonal distribution in Massachusetts, all individuals left inshore waters during winter months (Able and Fahay, 1998).

The diet of juveniles and adults consists of copepods, mysids, amphipods, cladocerans, fish eggs, squid, worms, molluscs, insects, algae, and detritus (Fay et al., 1983b). Atlantic silversides feed in large schools, preferring gravel and sand bars, open beaches, tidal creeks, river mouths, and marshes (Fay et al., 1983b).

Silversides live for only 1 or 2 years, usually dying after completing their first spawning (Fay et al., 1983b). Adults can reach sizes of up to 15 cm (5.9 in.) in total length (Froese and Pauly, 2001).

ATLANTIC SILVERSIDE
(*Menidia menidia*)

Family: Atherinidae (silversides).

Common names: Spearing, sperling, green smelt, sand smelt, white bait, capelin, shiner.[a]

Similar species: Inland silverside (*Menidia beryllina*).[a]

Geographic range: New Brunswick to northern Florida.[a]

Habitat: Sandy seashores and the mouths of inlets.[b]

Lifespan: One or 2 years. Often die after their first spawning.[a]

Fecundity: Females produce an average of 4,500 to 5,000 eggs per spawning season.[a]

Food Source: Zooplankton, fish eggs, squid, worms, molluscs, insects, algae, and detritus.[a]

Prey for: Striped bass, bluefish, weakfish, and Atlantic mackerel.[a,c]

Life stage information:

Eggs: demersal
- Found in shallow waters of estuarine intertidal zones.[a]
- Can be found adhering to submerged vegetation.[a]

Larvae:
- Range from 5.5 to 15.0 mm (0.2 to 0.6 in.) in size.[a]
- Sex is determined during the larval stage by the temperature regime. Colder temperatures tend to produce more females, and warmer temperatures produce more males.[a]

Adults:
- Overwinter in offshore marine waters.[d]
- Can reach sizes of up to 15 cm (5.9 in.) total length.[d]

[a] Fay et al., 1983b.
[b] Froese and Pauly, 2001.
[c] McBride, 1995.
[d] Able and Fahay, 1998.
Fish graphic from Government of Canada, 2001.

Tautog (*Tautoga onitis*)

The tautog is a member of the Labridae family, found in coastal areas from New Brunswick south to South Carolina. It is most abundant from Cape Cod, Massachusetts, to the Delaware Estuary (Atlantic States Marine Fisheries Commission, 2000e). Tautog are most frequently found close to shore, preferring rocky areas or other discontinuities such as pilings, jetties, or wrecks and salinities of greater than 25 ppt (Jury et al., 1994). They generally consume mussels, small crustaceans, and other molluscs (Steimle and Shaheen, 1999).

Tautog have historically supported a primarily recreational fishery. Since 1980, landings have averaged about 3,700 metric tons (8.1 million lb), with recreational catches accounting for 90 percent of the total (Atlantic States Marine Fisheries Commission, 2000e). The majority of Tautog are harvested by hook and line from private boats (Auster, 1989); however, there are also significant charter and party boat fisheries. Although commercial landings accounted for only 8.7 percent of the total from 1982 to 1991, commercial fishing has been increasing because of higher market prices (Atlantic States Marine Fisheries Commission, 2000h). There is evidence that the fishery is declining, with lower recreational and commercial catch rates. A survey conducted in Narragansett Bay in 1994 showed the lowest abundance of tautog ever recorded. Tautog are susceptible to overfishing, particularly because they experience slow growth and reproduction and tend to be easily found near wrecks and rock piles (Atlantic States Marine Fisheries Commission, 2000e).

Tautog migrate inshore in the spring to spawn in inshore waters. Spawning generally occurs between mid-May and August, peaks in June (Auster, 1989), and primarily takes place at the mouths of estuaries and along the inner continental shelf. In Narragansett Bay, tautog are known to return to the same spawning sites in the upper estuary each year. Fecundity increases with age until approximately age 16, when it begins to decline (Steimle and Shaheen, 1999). Females between 3 and 20 years were documented to contain between 5,000 and 673,500 mature eggs. The eggs are buoyant, and hatch out in approximately 2 to 3 days (Auster, 1989).

Larvae hatch out at 2 to 4 mm (0.079 to 0.157 in.) and migrate vertically in the water column, surfacing during the day and remaining near the bottom at night. Tautog are the most abundant larval species in Narragansett Bay. As they get older, they become more benthic (Steimle and Shaheen, 1999). Small juveniles will remain in estuaries year-round, in a home range of only several hundred meters, becoming torpid over the winter (Jury et al., 1994), while larger ones will join adults in deeper water. Small juveniles prefer vegetated habitats in depths of less than 1 m (3.3 ft) and are not observed in Narragansett Bay water deeper than 9 m (30 ft). Older juveniles and adults inhabit reef-like habitats that provide some type of cover (Steimle and Shaheen, 1999).

Tautog do not tend to migrate far offshore; however, adults move to deeper water in the fall, responding to decreases in temperature. Although they move to waters as deep as 45 m (148 ft), tautog select areas with rugged topography for cover. Adults return to coastal waters and estuaries to spawn when waters warm in the spring. Maturity is reached at about 3 to 4 years of age. Age 7 tautogs in Rhode Island had mean lengths of 348 mm (14 in.) for males and 301 mm (12 in.) for females. Males may live for over 30 years, while females may live to about 25 years of age (Steimle and Shaheen, 1999).

TAUTOG (*Tautoga onitis*)	**Food Source:** Juveniles feed on amphipods and copepods. Adults feed mainly on blue mussels, small crustaceans, and other molluscs.[a] **Prey for:** Smooth dogfish, barndoor skate, red hake, sea raven, goosefish, striped bass, silver hake, bluefish, seabirds.[a] **Life stage information:**
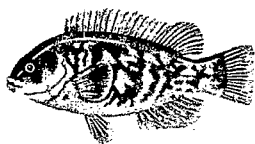
Family: Labridae (wrasses).

Common names: tautog, blackfish, white chin, chub, black porgy.[a]

Similar species: Cunner (*Tautogolabrus adspersus*).

Geographic range: Most abundant from Cape Cod, Massachusetts to the Delaware Estuary.[b]

Habitat: Rocky shoals around coastal shores.[c]

Lifespan: Maturity is reached at about 3 to 4 years. Maximum age of over 30 years for males, 25 years for females.[a]

Fecundity: Mature females may contain between 5,000 and 673,500 mature eggs.[d]

Eggs: buoyant
► Hatch out in 2 to 3 days.[a]

Larvae: pelagic
► Young larvae migrate vertically in the water column, surfacing during the day and remaining near the bottom at night.[a]

Juveniles: benthic
► Small juveniles prefer vegetated areas in depths less than 1 m (3.3 ft).[a]
► Larger juveniles prefer covered, reef-like habitats.[a]

Adults:
► Inhabit reef-like habitats that provide some type of cover.[a]
► Migrate inshore in late spring to spawn at the mouths of estuaries and along the inner continental shelf.[a]

[a] Steimle and Shaheen, 1999.
[b] Atlantic States Marine Fisheries Commission, 2000e.
[c] Scott and Scott, 1988.
[d] Auster, 1989.
Fish graphic from: State of Maine Division of Marine Resources, 2001c.

Windowpane (*Scophthalmus aquosus*)

Windowpane is a member of the Scophthalmidae family (left-eye flounders) found from the Gulf of St. Lawrence to Florida, inhabiting estuarine and shallow continental shelf waters less than 56 m (184 ft) deep (Able and Fahay, 1998). They have been found in areas with muddy or sandy bottoms, water temperatures ranging from 0 to 24°C (0 to 75 °F), and salinities of 5.5 to 36 ppt (Chang et al., 1999).

Spawning occurs over the continental shelf and in estuaries, but not in waters over 20 °C (68 °F) (Kaiser and Neuman, 1995). The timing of spawning varies with location: in Mid-Atlantic Bight waters, spawning occurs from April through December, peaking in May and October, while on Georges Bank spawning occurs during summer and peaks in July and August (Hendrickson, 2000). The estimated average lifetime fecundity of females is 100,000 eggs (New England Power Company and Marine Research Inc., 1995). Eggs are buoyant and hatch out in 8 days at a water temperature of 11°C (52 °F) (Chang et al., 1999). Eggs and larvae are planktonic, but movements are poorly understood. Between 6.5 and 13.0 mm (0.256 and 0.512 in.), eye migration occurs and the body becomes more laterally compressed (Able and Fahay, 1998). Juveniles appear to use estuaries as nursing areas, and then move to offshore waters in the fall (Kaiser and Neuman, 1995).

Although windowpane have been found to migrate 130 km (81 miles) in a few months, most researchers agree that windowpane generally do not migrate long distances (Chang et al., 1999).

Windowpane reach sexual maturity at age 3 or 4 (Hendrickson, 2000). Adults reach a maximum length of approximately 46 cm (18 in.), and may live up to 7 years (Scott and Scott, 1988).

While windowpane has not been a particularly important commercial fish, it may become more so as stocks of summer flounder are overfished. Commercial catches began in 1943, and through 1975 windowpane was harvested as part of an industrial fishery. Landings in southern New England peaked in 1985 at 2,100 metric tons (4.6 million lb), decreased to a low of 100 metric tons (0.2 million lb) in 1995, and have remained below 200 metric tons (0.4 million lb) since then. Populations have also decreased since the 1980's, and overfishing is suspected as a main cause (Hendrickson, 2000).

WINDOWPANE
(*Scophthalmus aquosus*)

Family: Scophthalmidae (left-eye flounder).

Common names: windowpane.

Similar species: turbot (*Scophthalmus maximus*), brill (*Scophthalmus rhombus*).

Geographic range: From the Gulf of St. Lawrence to Florida.[a]

Habitat: Estuarine and shallow continental shelf waters of depths less than 56 m (184 ft).[a]

Lifespan: Approximately 7 years.[b]

Fecundity: Average lifetime fecundity of 100,000 eggs.[e]

Food Source: Young consume mysids; adults feed on sand shrimp, small fish (up to 10 cm), crustaceans, molluscs, and seaweed.

Prey for: Spiny dogfish, thorny skate, goosefish, Atlantic cod, black sea bass, weakfish, and summer flounder.[d]

Life stage information:

Eggs: buoyant
- Eggs are buoyant and hatch out in 8 days at a water temperature of 11 °C.[d]

Larvae: pelagic
- Eye migration occurs and the body becomes more laterally compressed.[d]

Juveniles:
- Use estuaries as nursing areas, returning to offshore waters in the fall.[e]

Adults:
- Reach a maximum length of approximately 46 cm.[b]
- Seasonally migrate to deeper waters in late autumn to overwinter.[d]

[a] Able and Fahay, 1998.
[b] Scott and Scott, 1988.
[e] New England Power Company and Marine Research Inc., 1995.
[d] Chang et al., 1999.
[e] Kaiser and Neuman, 1995.
Fish graphic from NEFSC, 2001.

Winter flounder (*Pleuronectes americanus*)

Winter flounder is a benthic flatfish of the family Pleuronectidae (righteye flounders), which is found in estuarine and continental shelf habitats. Its range extends from the southern edge of the Grand Banks south to Georgia (Buckley, 1989b). It is a bottom feeder, occupying sandy or muddy habitats and feeding on bottom-dwelling organisms such as shrimp, amphipods, crabs, urchins, and snails (Froese and Pauly, 2001).

Both commercial and recreational fisheries for winter flounder are important. U.S. commercial and recreational fisheries are managed under the New England Fishery Management Council's Multispecies Fishery Management Plan and the Atlantic States Marine Fisheries Commission's Fishery Management Plan for Inshore Stocks of Winter Flounder (NEFSC, 2000d). Three groups are recognized for management and assessment purposes: Gulf of Maine, Southern New England-Mid Atlantic, and Georges Bank. Management currently focuses on reducing fishing levels to reverse declining trends and rebuild stocks. The Gulf of Maine stock is currently considered overfished (NEFSC, 2000d). Although improvements in stock condition will depend on reduced harvest, the long-term potential catch (maximum sustainable yield) has not been determined.

The winter flounder is essentially nonmigratory, but there are seasonal patterns in movements within the estuary. Winter flounder south of Cape Cod generally move to deeper, cooler water in summer and return to shallower areas in the fall, possibly in response to temperature changes (Howe and Coates, 1975; Scott and Scott, 1988).

Spawning occurs between January and May in New England, with peaks in the Massachusetts area in February and March (Bigelow and Schroeder, 1953). Spawning habitat is generally in shallow water over a sandy or muddy bottom (Scott and Scott, 1988). Adult fish tend to leave the shallow water in autumn to spawn at the head of estuaries in late winter. The majority of spawning takes place in a salinity range of 31 to 33 ppt and a water temperature range of 0 to 3 °C (32 to 37 °F). Females will usually produce between 500,000 and 1.5 million eggs annually, which sink to the bottom in clusters. The eggs are about 0.74 to 0.85 mm (approximately 0.03 in.) in diameter, and hatch in approximately 15 to 18 days (Bigelow and Schroeder, 1953).

Larvae are about 3.0 to 3.5 mm (0.1 in.) total length when they hatch out. They develop and metamorphose over 2 to 3 months, with growth rates controlled by water temperature (Bigelow and Schroeder, 1953). Larval growth appears to be optimal with a slow increase from spawning temperatures of 2 °C (36 °F) to approximately 10 °C (50 °F; Buckley, 1982). Larvae depend on light and vision to feed during the day and do not feed at night (Buckley, 1989b). Juveniles tend to remain in shallow spawning waters, and stay on the ocean bottom (Scott and Scott, 1988).

Fifty percent of females reach maturity at age 2 or 3 in the waters of Georges Bank, while they may not mature until age 5 in more northern areas such as near Newfoundland. Females are generally 22.5 to 31.5 cm (8 to 12.4 in.) long at maturity (Howell et al., 1992).

Winter flounder supports important commercial and recreational fisheries in the area, as it is the thickest and meatiest of the common New England flatfish (Bigelow and Schroeder, 1953). Annual commercial landings in New England declined from 17,083 metric tons (37.7 million lb) in 1981 to 3,223 metric tons (7.1 million lb) in 1994. The harvest has increased somewhat since then, rising to 5,123 metric tons (11.3 million lb) in 2000 (personal communication, National Marine Fisheries Society, Fish Statistics and Economics Division, Silver Spring, MD, January 16, 2002.). Winter flounder is ecologically important as a prey species for larger estuarine and coastal fish such as striped bass (*Morone saxatilis*) and bluefish (*Pomatomus saltatrix*) (Buckley, 1989b).

WINTER FLOUNDER
(*Pleuronectes americanus*)

Family: Pleuronectidae (righteye flounders).

Common names: Blackback flounder, lemon sole, black flounder.[a]

Similar species: American plaice (*Hippoglossoides platessoides*), European plaice (*P. platessus*).

Geographic range: From the southern edge of the Grand Banks south to Georgia.[b]

Habitat: Bottom dweller. Found in coastal marine waters.[c]

Lifespan: May live up to 15 years.

Fecundity: Females produce between 500,000 and 1.5 million eggs annually.[a]

Food source: Bottom-dwelling organisms such as shrimp, annelid worms, amphipods, crabs, urchins and snails.[a]

Prey for: Striped bass, bluefish.[b]

Life stage information:

Eggs: demersal
► Approximately 0.74 to 0.85 mm (0.03 in.) in diameter.[a]
► Hatch in approximately 15 to 18 days.[a]

Larvae: semi-pelagic
► Approximately 3.0 to 3.5 (0.1 in.) mm total length when they hatch out.[a]

Juveniles: demersal
► Once winter flounder enter the juvenile stage, they remain benthic, preferring sandy bottomed substrates.[d]

Adults:
► Females mature at ages 2 and 3.[e]
► Migrate seasonally to offshore waters in the summer, and inshore waters in the winter.[b]

[a] Bigelow and Schroeder, 1953.
[b] Buckley, 1989b.
[c] Scott and Scott, 1988.
[d] Grimes et al., 1989.
[e] Howell et al., 1992.
Fish graphic from State of Maine Division of Marine Resources, 2001d.

F3-3 BRAYTON POINT GENERATING STATION'S I&E SAMPLING METHODS

Impingement sampling was conducted from 1972 through 1998. Entrainment sampling has been conducted periodically in the discharge of units 1, 2, and 3 since 1972. The following sections describe these sampling programs.

F3-3.1 Impingement Monitoring

Impingement sampling of the revolving screens at units 1,2, and 3 was conducted from 1972 through 1998. Sampling was conducted year-round, as long as each unit was in operation (USGen New England, 2001).

The traveling screens for units 1, 2, and 3 have 9.5 mm (0.375 in.) mesh (PG&E National Energy Group, 2001). During impingement sampling, screenwash water was diverted to in-line collection tanks. All fish collected were identified and counted, although counts were reported separately only for selected species; all other species were reported as a group.

From 1972 to 1996, impingement was monitored three times per week by placing a trap in the sluiceway downstream of the revolving screens while the wash system was in operation. All of the fish collected in the trap were counted, identified, and measured. Unit 3 screens, which have the highest impingement rate, were washed three times a day at 8 to 12 hour intervals. Each of the three weekly collections took place at one of these wash periods. Units 1 and 2 were washed once per day, and only two weekly collections were done at these units (New England Power Company and Marine Research Inc., 1998).

Since 1997, the revolving screens have run continuously and are monitored daily. To monitor impingement rates, the collection tank is periodically emptied and left in place for a 4 to 8 hour interval (PG&E Generating and Marine Research Inc., 1999).

To derive annual estimates, the facility extrapolated counts from a weekly sampling period to derive a weekly total (PG&E Generating and Marine Research Inc., 1999). Weekly totals were then summed to estimate an annual total. It should be noted that the impingement data set used (1974-1983) likely represents an underestimate because that time period did not include or record any of the occasional large-scale impingement events for menhaden that have occurred at Brayton Point over the years. For example, in early 2002 an impingement event occurred in which approximately 25,000 menhaden were impinged from January 5 through February 3, 2002, and then another approximately 6,400 were impinged from February 11 to February 16, 2002.

F3-3.2 Entrainment Monitoring

Entrainment sampling of selected species was conducted in the discharge stream of units 1, 2, and 3 from June 1972 through December 1985. Until the middle of 1984, entrainment was sampled for units 1,2, and 3 only. When unit 4 switched to once-through cooling in 1984, sampling was also conducted near the unit 4 discharge headwall from February through mid-May, except when unit 4 was operating in piggyback mode (see Chapter F2; PG&E Generating and Marine Research Inc.,1999; USGen New England, 2001; PG&E National Energy Group, 2001). Sampling ceased from 1986 through 1991. In January 1992, entrainment sampling was reinitiated during the larval season (February through mid-May) for winter flounder only, as part of an examination of the winter flounder stock decline in Mount Hope Bay (USGen New England, 2001). Initially, winter flounder entrainment was classified only as larvae or eggs, but from 1978 on, four larval stages were classified (PG&E Generating and Marine Research Inc., 1999). Other species were not classified into separate larval stages.

From 1972 to 1979, sampling was conducted monthly from September through February and weekly from March through August. In 1979, the sampling frequency was increased to every 4 to 5 days from March through August (Marine Research Inc. and New England Power Company, 1981). After 1992, the sampling schedule was again changed so that sampling was conducted from February through mid-May every 4 to 5 days.

Sampling techniques have remained generally the same since 1972 (PG&E Generating and Marine Research Inc., 1999). Collection was completed by streaming 0.333 mm (0.01 in.) or 0.505 mm (0.02 in.) mesh, 60 cm (24 in.) diameter plankton nets in the discharge streams of the units. Three samples were taken at each sampling event (PG&E National Energy Group, 2001).

Differences in sampling gear mesh size made it necessary to standardize the entrainment data. Samples from the finer 0.333 mm (0.01 in.) mesh screens were adjusted by the facility to make the data comparable to the 0.505 mm (0.02 in.) mesh screens, because this size mesh was used in the past to develop baywide winter flounder abundance estimates. An adjustment factor derived from a mesh comparison study conducted at Brayton Point in 1994 (New England Power Company & Marine Research Inc., 1995) was used to account for the extrusion of smaller larvae that would have occurred through the larger mesh net.

To derive annual estimates, the facility standardized larval densities to the number of larvae per 100 m^3 (26,000 gallons) of water within each sampling day (PG&E Generating and Marine Research Inc., 1999). The facility extrapolated these larval

densities to annual estimates using the reported monthly average circulating water volume. Since 1992, estimates of larval winter flounder entrainment were determined separately for units 1, 2, and 3 combined and for unit 4 alone.

F3-4 ANNUAL IMPINGEMENT AND ENTRAINMENT

There are a number of deficiencies in Brayton Point's time series of I&E data. First, I&E data collected over the past decade or so probably underestimate potential I&E of Mount Hope Bay fish species, since the populations of most fish species in the area are severely depressed (Gibson, 1996). In addition, Brayton Point's entrainment monitoring since 1985 has included only winter flounder. Therefore, to estimate potential I&E at Brayton Point under current operating conditions for as many species as possible, EPA used the most comprehensive historical time series of I&E data for Brayton Point (1974-1983) and . adjusted these rates for the facility's current operations.

EPA's adjustment of historical I&E rates to reflect current operations considered (1) the effectiveness of the angled screens on Unit 4, which the facility reports reduce impingement by 55.4%, and (2) the higher current intake flow resulting from the conversion of Unit 4 to once through cooling in 1984 (see Chapter F2 for technical details). EPA applied a scaling factor of 1.142 to impingement and entrainment data to account for the higher current intake flow and a scaling factor of 0.931 to impingement data to account for the angled screen. The flow scaling factor was based on the annualized mean operational flow (Units 1-3) during 1974-1983 of 720 MGD, and the current annualized mean operational flow (Units 1-4) of 822 MGD. The value 822 MGD for current annualized mean operational flow includes consideration of the fact that Unit 4 is operated in piggyback mode during selected months. This flow estimate was derived from records of flow provided by the facility. The use of the scaling factors increased the 1974-1983 entrainment rates by 14.2% and impingement rates by 6.4%.

EPA evaluated its estimates of annual I&E under current Brayton Point operations using the methods described in Chapter A5 of Part A of this document. The species-specific life history values used by EPA for its analyses are presented in Appendix F1. Table F3-2 displays EPA's estimates of annual impingement (numbers of organisms) by species. Table F3-3 displays those numbers expressed as age 1 equivalents, Table F3-4 displays impingement of fishery species as yield lost to fisheries, and Table F3-5 displays annual impingement expressed as production foregone. Tables F3-6 through F3-9 display the same information for entrainment at Brayton Point.

F3-5 SUMMARY

Table F3-10 summarizes EPA's estimates of annual I&E impacts of Brayton Point's current operations on Mount Hope Bay fish species. Results indicate that, on average, current operations may be expected to result in annual impingement of about 45,000 organisms. This represents 69,329 age 1 equivalents, 5,091 pounds of lost fishery yield, and 2,808 pounds of production foregone each year. Note that impingement losses expressed as age 1 equivalents are higher than raw losses (the actual number of organisms of all life stages that are impinged). This is because the ages of impinged individuals are assumed to be distributed across the interval between the start of year 1 and the start of year 2, and then the losses are normalized back to the start of year 1 by accounting for mortality during this interval (for details see Chapter A5).

Most impinged species are the forage fish hogchoker, Atlantic silverside, alewife, and bay anchovy, and the fishery species silver hake and winter flounder. There have also been episodes of high impingement of Atlantic menhaden, reaching several hundred thousand losses within a few weeks (Phil Colarusso, EPA Region 1, *personal communication*, February 2002). The most recent event, in winter 2002, involved the impingement of over 25,000 Atlantic menhaden. Annual entrainment resulting from current operations is estimated to average over 16.7 billion organisms, representing over 3.8 million age 1 equivalents, 70,410 pounds of lost fishery yield, and 69.5 million pounds of production foregone each year.

Most entrained organisms are the forage species American sand lance, bay anchovy, and seaboard goby and the fishery species winter flounder. The estimated average loss of over a half million age 1 equivalent winter flounder each year is thought to represent most of the local stock of winter flounder according to estimates by the Rhode Island Division of Fish and Wildlife (Phil Colarusso, EPA Region 1, *personal communication*, March 14, 2002).

The economic value of Brayton Point's I&E losses is discussed in Chapters F4 (benefits transfer) and F5 (habitat-based replacement cost). The potential benefits of reducing these losses with the proposed rule are discussed in Chapter F6.

Table F3-2: EPA's Estimate of Brayton Point Annual Impingement (numbers of organisms) Derived from Historical Impingement Rates Adjusted for Current Operations

Year	Alewife	Atlantic Menhaden	Atlantic Silverside	Bay Anchovy	Butterfish	Hogchoker	Rainbow Smelt	Silver Hake	Striped Killifish	Tautog	Threespine Stickleback	Weakfish	White Perch	Window-pane	Winter Flounder
1974	2,450	12,438	4,020	859	264	2,142	2,450	3,428	89	215	3,468	157	2,104	304	17,135
1975	1,928	1,681	684	15,879	102	1,634	129	3,691	73	363	1,907	307	1,571	234	4,718
1976	5,550	897	1,347	1,470	15	5,175	312	1,295	429	409	1,608	182	4,507	348	6,314
1977	37,627	2,571	3,287	2,279	346	22,684	591	19,065	1,898	2,709	822	1,889	4,467	2,025	14,397
1978	3,090	1,671	17,935	684	21	10,614	3,515	8,433	213	2,500	1,109	468	1,319	2,548	24,941
1979	1,926	465	5,270	5,284	87	2,983	607	6,868	364	338	5,134	269	812	1,130	4,087
1980	1,080	872	4,303	806	740	4,438	241	883	576	684	1,025	140	786	1,540	7,891
1981	319	36	4,740	146	38	1,630	412	391	470	780	1,057	37	418	2,008	5,841
1982	4,986	129	3,567	3,053	143	16,244	267	3,130	66	3,078	449	1,560	803	727	2,986
1983	1,023	0	2,690	3,036	6	2,297	171	1,816	0	235	387	22	439	74	2,172
Mean	5,998	2,076	4,784	3,350	176	6,984	870	4,900	418	1,131	1,697	503	1,723	1,094	9,048
Minimum	319	0	684	146	6	1,630	129	391	0	215	387	22	418	74	2,172
Maximum	37,627	12,438	17,935	15,879	740	22,684	3,515	19,065	1,898	3,078	5,134	1,889	4,507	2,548	24,941
SD	11,240	3,736	4,839	4,662	228	7,256	1,153	5,605	557	1,148	1,500	661	1,546	889	7,402
Total	59,980	20,760	47,842	33,496	1,762	69,840	8,695	49,001	4,178	11,310	16,967	5,032	17,225	10,939	90,481

0=Sampled, but none collected.
Wed Feb 13 11:40:28 MST 2002 Raw.losses. IMPINGEMENT; Plant:brayton.projected;
PATHNAME:P:/Intake/Brayton/Brayton_Science/scodes/tables.output.projected01/raw.losses.imp.brayton.projected.csv

Table F3-3: EPA's Estimate of Annual Impingement at Brayton Point Derived from Historical Impingement Rates Adjusted for Current Operations and Expressed as Age 1 Equivalents

Year	Alewife	Atlantic Menhaden	Atlantic Silverside	Bay Anchovy	Butter-fish	Hog-choker	Rainbow Smelt	Silver Hake	Striped Killifish	Tautog	Threespine Stickleback	Weakfish	White Perch	Windowpane	Winter Flounder
1974	3,617	15,717	7,657	1,562	415	3,977	3,602	4,038	122	234	5,584	188	2,805	367	25,756
1975	2,846	2,124	1,303	28,870	161	3,033	189	4,349	101	394	3,071	366	2,094	282	7,091
1976	8,194	1,133	2,567	2,672	23	9,609	458	1,526	587	445	2,589	217	6,009	420	9,491
1977	55,547	3,249	6,261	4,144	544	42,121	869	22,460	2,600	2,945	1,324	2,251	5,955	2,444	21,641
1978	4,562	2,111	34,161	1,243	33	19,708	5,166	9,935	291	2,718	1,786	558	1,758	3,076	37,489
1979	2,843	587	10,037	9,608	137	5,539	893	8,091	498	368	8,268	321	1,083	1,365	6,143
1980	1,595	1,102	8,196	1,466	1,166	8,240	355	1,040	790	743	1,651	167	1,048	1,859	11,861
1981	471	46	9,028	265	60	3,027	605	461	644	848	1,702	44	557	2,424	8,779
1982	7,360	163	6,794	5,551	224	30,162	392	3,687	90	3,346	723	1,860	1,071	878	4,489
1983	1,510	0	5,123	5,520	-10	4,265	252	2,140	0	256	623	27	586	90	3,264
Mean	8,855	2,623	9,113	6,090	278	12,968	1,278	5,773	572	1,230	2,732	600	2,297	1,320	13,601
Minimum	471	0	1,303	265	10	3,027	189	461	0	234	623	27	557	90	3,264
Maximum	55,547	15,717	34,161	28,870	1,166	42,121	5,166	22,460	2,600	3,346	8,268	2,251	6,009	3,076	37,489
SD	16,593	4,721	9,217	8,477	359	13,474	1,694	6,603	763	1,248	2,415	788	2,061	1,073	11,126
Total	88,546	26,232	91,126	60,902	2,775	129,681	12,781	57,727	5,724	12,296	27,321	5,998	22,967	13,204	136,005

Note: Impingement losses expressed as age 1 equivalents are larger than raw losses (the actual number of organisms impinged). This is because the ages of impinged individuals are assumed to be distributed across the interval between the start of year 1 and the start of year 2, and then the losses are normalized back to the start of year 1 by accounting for mortality during this interval (for details, see description of S*j in Chapter A2, Equation 4 and Equation 5). This type of adjustment is applied to all raw loss records, but the effect is not readily apparent among entrainment losses because the majority of entrained fish are younger than age 1
0=Sampled, but none collected.
Wed Feb 13 11:51:10 MST 2002 ;Results; I Plant: brayton.projected ; Units: equivalent.sums Pathname:
P:/Intake/Brayton/Brayton_Science/scodes/tables.output.projected01/I.equivalent.sums.brayton.projected.csv

Table F3-4: EPA's Estimate of Annual Impingement of Fishery Species at Brayton Point Derived from Historical Impingement Rates Adjusted for Current Operations and Expressed as Yield Lost to Fisheries (in pounds)

Year	Atlantic Menhaden	Butterfish	Rainbow Smelt	Silver Hake	Tautog	Weakfish	White Perch	Windowpane	Winter Flounder
1974	1,845	10	4	1,536	104	131	31	34	2,773
1975	249	4	0	1,654	176	256	23	26	764
1976	133	1	1	580	198	151	66	39	1,022
1977	382	14	1	8,543	1,312	1,572	65	226	2,330
1978	248	1	6	3,779	1,211	390	19	285	4,037
1979	69	3	1	3,078	164	224	12	126	661
1980	129	29	0	396	331	117	12	172	1,277
1981	5	2	1	175	378	31	6	224	945
1982	19	6	0	1,403	1,491	1,299	12	81	483
1983	0	0	0	814	114	19	6	8	351
Mean	308	7	1	2,196	548	419	25	122	1,464
Minimum	0	0	0	175	104	19	6	8	351
Maximum	1,845	29	6	8,543	1,491	1,572	66	285	4,037
SD	554	9	2	2,512	556	550	23	99	1,198
Total	3,080	70	15	21,958	5,478	4,189	253	1,223	14,645

0=Sampled, but none collected.
Wed Feb 13 11:51:28 MST 2002 ;Results; I Plant: brayton.projected ; Units: yield Pathname:
P:/Intake/Brayton/Brayton_Science/scodes/tables.output.projected01/I.yield.brayton.projected.csv

Table F3-5: EPA's Estimate of Annual Impingement at Brayton Point Derived from Historical Impingement Rates Adjusted for Current Operations and Expressed as Production Foregone (in pounds)

Year	Alewife	Atlantic Menhaden	Atlantic Silverside	Bay Anchovy	Butter-fish	Hogchoker	Rainbow Smelt	Silver Hake	Striped Killifish	Tautog	Threespine Stickleback	Weakfish	White Perch	Window-pane	Winter Flounder
1974	69	1,348	2	0	4	2	21	718	1	40	1	43	99	17	1,664
1975	54	182	0	4	2	1	1	773	1	67	1	84	74	13	458
1976	155	97	1	0	0	4	3	271	4	75	1	50	212	19	613
1977	1,054	279	1	1	5	19	5	3,994	16	499	0	515	210	112	1,398
1978	87	181	7	0	0	9	30	1,767	2	461	0	128	62	141	2,422
1979	54	50	2	1	1	2	5	1,439	3	62	2	73	38	63	397
1980	30	95	2	0	11	4	2	185	5	126	0	38	37	85	766
1981	9	4	2	0	1	1	4	82	4	144	0	10	20	111	567
1982	140	14	1	1	2	14	2	656	1	567	0	425	38	40	290
1983	29	0	1	1	0	2	1	381	0	43	0	6	21	4	211
Mean	168	225	2	1	3	6	7	1,026	4	208	1	137	81	61	879
Minimum	9	0	0	0	0	1	1	82	0	40	0	6	20	4	211
Maximum	1,054	1,348	7	4	11	19	30	3,994	16	567	2	515	212	141	2,422
SD	315	405	2	1	3	6	10	1,174	5	212	1	180	73	49	719
Total	1,680	2,251	18	8	26	59	74	10,265	35	2,084	7	1,372	810	605	8,788

0=Sampled, but none collected.
Wed Feb 13 11:51:19 MST 2002 ;Results; I Plant: brayton.projected ; Units: annual.prod.forg Pathname:
P:/Intake/Brayton/Brayton_Science/scodes/tables.output.projected01/I.annual.prod.forg.brayton.projected.csv

Table F3-6: EPA's Estimate of Brayton Point Annual Entrainment (numbers of organisms) Derived from Historical Entrainment Rates Adjusted
Current Operations

Year	Alewife	American Sand Lance	Atlantic Menhaden	Atlantic Silverside	Bay Anchovy	Hogchoker	Rainbow Smelt	Scup	Seaboard Goby
1974	848,337	3,908,121	448,538,093	25,034,653	3,440,864,344	0	9,317,827	0	533,634,710
1975	0	29,722,440	1,958,145,594	2,054,000	9,286,758,903	25,143,906	899,822	542,291	740,278,378
1976	5,913,736	2,770,430	2,921,793,521	51,003,930	12,676,121,895	150,802,186	84,349	0	894,537,113
1977	1,578,638	56,329,070	128,713,025	10,607,391	7,395,970,990	88,073,974	0	0	432,875,632
1978	2,091,279	60,311,262	73,693,538	1,542,365	8,672,482,263	67,483,651	1,442,659	0	289,763,158
1979	0	191,610,863	115,900,493	9,402,729	13,609,577,224	64,661,257	1,420,061	0	97,031,131
1980	0	18,953,510	385,593,622	6,601,879	11,292,722,522	259,609,635	1,615,204	12,750,912	291,375,379
1981	0	429,543,642	3,915,878	34,957,087	6,349,504,627	120,298,108	157,396	13,221,566	524,387,972
1982	262,627	21,794,637	17,192,935	16,515,078	11,324,946,303	212,128,674	91,085	1,995,943	417,135,869
1983	70,385	30,258,451	197,688,008	29,879,285	18,093,306,204	77,957,641	18,375,305	0	400,688,890
Mean	1,076,500	84,520,243	625,117,471	18,759,840	10,214,225,528	106,615,903	3,340,371	2,851,071	462,170,823
Minimum	0	2,770,430	3,915,878	1,542,365	3,440,864,344	0	0	0	97,031,131
Maximum	5,913,736	429,543,642	2,921,793,521	51,003,930	18,093,306,204	259,609,635	18,375,305	13,221,566	894,537,113
SD	1,857,205	133,021,447	993,768,589	16,150,153	4,137,368,061	81,063,020	5,967,035	5,378,841	229,044,233
Total	10,765,003	845,202,427	6,251,174,706	187,598,398	102,142,255,276	1,066,159,032	33,403,707	28,510,713	4,621,708,234

0=Sampled, but none collected.
Wed Feb 13 11:40:28 MST 2002 Raw.losses. ENTRAINMENT; Plant:brayton.projected;
PATHNAME:P:/Intake/Brayton/Brayton_Science/scodes/tables.output.projected01/raw.losses.ent.brayton.projected.csv

Table F3-6: EPA's Estimate of Brayton Point Annual Entrainment (numbers of organisms) Derived from Historical Entrainment Rates Adjusted for Current Operations (cont.)

Year	Silver Hake	Tautog	Threespine Stickleback	Weakfish	White Perch	Windowpane	Winter Flounder
1974	0	4,095,249,317	0	30,634,273	0	115,700,207	986,595,306
1975	0	2,562,125,750	0	31,509,825	0	277,646,365	859,825,130
1976	0	10,513,607,464	0	0	0	136,333,892	1,217,354,953
1977	0	2,178,251,158	0	14,404,360	0	101,632,473	381,833,868
1978	196,548	5,862,184,934	0	28,303,368	57,788	590,926,739	1,359,249,041
1979	0	3,132,662,371	0	83,878,964	330,550	527,866,367	668,918,507
1980	0	2,635,758,729	0	344,491,911	0	510,692,636	724,134,196
1981	0	1,128,620,504	0	40,293,328	0	257,717,460	356,754,776
1982	115,756	2,517,050,246	167,498	59,283,063	49,320	698,080,809	1,127,118,545
1983	122,201	4,911,927,271	0	31,941,824	112,843	466,673,500	277,046,674
Mean	43,450	3,953,743,774	16,750	66,474,092	55,050	368,327,045	795,883,100
Minimum	0	1,128,620,504	0	0	0	101,632,473	277,046,674
Maximum	196,548	10,513,607,464	167,498	344,491,911	330,550	698,080,809	1,359,249,041
SD	73,094	2,690,678,198	52,967	100,344,139	104,064	216,770,630	380,047,652
Total	434,505	39,537,437,744	167,498	664,740,916	550,501	3,683,270,450	7,958,830,996

0=Sampled, but none collected.

Wed Feb 13 11:40:28 MST 2002 Raw.losses. ENTRAINMENT; Plant:brayton.projected;

PATHNAME:P:/Intake/Brayton/Brayton_Science/scodes/tables.output.projected01/raw.losses.ent.brayton.projected.csv

Table F3-7: EPA's Estimate of Annual Entrainment at Brayton Point Derived from Historical Entrainment Rates Adjusted for Current Operations and Expressed as Age 1 Equivalents

Year	Alewife	American Sand Lance	Atlantic Menhaden	Atlantic Silverside	Bay Anchovy	Hog-choker	Rainbow Smelt	Scup	Seaboard Goby	Silver Hake	Tautog	Threespine Stickleback	Weak-fish	White Perch	Window-pane	Winter Flounder
1974	528	20,985	15,764	10,849	471,088	0	20,403	0	1,749,359	0	30,833	0	563	0	2,518	27,124
1975	0	159,598	43,032	890	1,213,596	8,613	4,812	394	2,426,777	0	20,864	0	579	0	6,108	115,620
1976	1,580	14,876	32,550	22,103	1,161,615	43,421	1,022	0	2,922,733	0	78,264	0	0	0	2,959	131,571
1977	982	302,466	2,671	4,597	954,624	34,152	0	0	1,419,051	0	16,686	0	265	0	2,311	31,646
1978	1,301	317,798	939	668	1,462,657	24,687	12,476	0	949,612	10	45,078	0	520	0	12,195	1,866,911
1979	0	1,028,877	1,527	2,927	1,483,081	22,544	29,920	0	318,087	0	23,962	0	500	1	10,237	691,878
1980	0	101,773	5,974	2,822	1,120,273	81,165	34,032	1,812	955,185	0	21,101	0	1,757	0	9,942	559,826
1981	0	2,306,485	69	15,074	644,120	38,212	3,316	1,879	1,719,046	0	8,499	0	226	0	4,850	332,930
1982	163	117,029	187	7,129	1,651,529	64,000	1,919	1,008	1,365,625	5	19,471	6,526	345	0	13,507	805,497
1983	44	162,476	2,515	12,931	2,147,915	24,687	387,158	0	1,312,882	1	36,732	0	161	0	9,064	508,141
Mean	460	453,236	10,523	7,999	1,231,050	34,148	49,506	509	1,513,836	2	30,149	653	492	0	7,369	507,114
Minimum	0	14,876	69	668	471,088	0	0	0	318,087	0	8,499	0	0	0	2,311	27,124
Maximum	1,580	2,306,485	43,032	22,103	2,147,915	81,165	387,158	1,879	2,922,733	10	78,264	6,526	1,757	1	13,507	1,866,911
SD	610	714,399	15,293	7,076	488,813	24,349	119,279	774	748,897	3	19,866	2,064	484	0	4,152	553,383
Total	4,597	4,532,363	105,229	79,992	12,310,498	341,480	495,058	5,093	15,138,358	17	301,490	6,526	4,917	1	73,691	5,071,144

0=Sampled, but none collected.
Wed Feb 13 11:51:07 MST 2002 ;Results; E Plant: brayton.projected ; Units: equivalent.sums Pathname:
P:/Intake/Brayton/Brayton_Science/scodes/tables.output.projected01/E.equivalent.sums.brayton.projected.csv

Table F3-8: EPA's Estimate of Annual Entrainment of Fishery Species at Brayton Point Derived from Historical Entrainment Rates Adjusted for Current Operations and Expressed as Yield Lost to Fisheries (in pounds)

Year	Atlantic Menhaden	Rainbow Smelt	Scup	Silver Hake	Tautog	Weakfish	Windowpane	Winter Flounder
1974	1,851	23	0	0	13,737	393	233	2,921
1975	5,053	5	41	0	9,296	404	566	12,450
1976	3,822	1	0	0	34,870	0	274	14,167
1977	314	0	0	0	7,434	185	214	3,408
1978	110	14	0	4	20,084	363	1,130	201,025
1979	179	34	0	0	10,676	349	948	74,500
1980	701	39	190	0	9,401	1,227	921	60,281
1981	8	4	197	0	3,787	158	449	35,849
1982	22	2	106	2	8,675	241	1,251	86,734
1983	295	440	0	1	16,366	112	840	54,716
Mean	1,236	56	53	1	13,433	343	683	54,605
Minimum	8	0	0	0	3,787	0	214	2,921
Maximum	5,053	440	197	4	34,870	1,227	1,251	201,025
SD	1,796	136	81	1	8,851	338	385	59,587
Total	12,356	563	535	6	134,326	3,434	6,826	546,050

0=Sampled, but none collected.
Wed Feb 13 11:51:26 MST 2002 ;Results; E Plant: brayton.projected ; Units: yield Pathname:
P:/Intake/Brayton_Science/scodes/tables.output.projected01/E.yield.brayton.projected.csv

Table F3-9: EPA's Estimate of Annual Entrainment at Brayton Point Derived from Historical Entrainment Rates Adjusted for Current Operations and Expressed as Production Foregone (in pounds)

Year	Ale-wife	American Sand Lance	Atlantic Menhaden	Atlantic Silverside	Bay Anchovy	Hog-choker	Rain-bow Smelt	Scup	Sea-board Goby	Silver Hake	Tautog	Threespine Stickleback	Weakfish	White Perch	Window-pane	Winter Flounder
1974	563	80	727,705	11,798	482,933	0	3,635	0	886	0	62,594,114	0	401,167	0	56,227	5,589,405
1975	0	605	2,122,523	968	1,326,997	18,901	551	23	1,230	0	38,915,872	0	412,633	0	134,698	6,162,398
1976	2,623	56	1,872,731	24,036	2,013,015	118,326	92	0	2,466	0	160,835,134	0	0	0	66,285	8,273,869
1977	1,047	1,147	133,060	4,999	1,061,663	63,806	0	0	719	0	33,249,061	0	188,630	0	49,040	2,460,091
1978	1,387	1,392	52,050	727	1,104,995	49,782	1,219	0	510	572	89,454,342	0	370,643	76	289,536	6,696,994
1979	0	3,901	83,937	3,616	2,065,095	48,369	2,443	0	161	0	47,822,827	0	3,338,452	433	260,963	3,063,855
1980	0	386	315,765	3,084	1,758,507	199,834	2,779	8,110	484	0	40,090,691	0	14,349,676	0	252,339	3,294,944
1981	0	8,745	3,550	16,421	982,948	92,237	271	8,409	871	0	17,250,213	0	1,633,686	0	127,934	1,688,902
1982	174	444	10,852	7,763	1,548,304	164,685	157	533	877	305	38,391,085	278	2,377,063	65	345,225	5,195,371
1983	47	616	139,510	14,069	2,673,623	59,819	31,613	0	731	207	75,115,592	0	1,334,689	148	230,663	1,379,929
Mean	584	1,737	546,168	8,748	1,501,808	81,576	4,276	1,707	894	108	60,371,893	28	2,440,664	72	181,291	4,380,576
Minimum	0	56	3,550	727	482,933	0	0	0	161	0	17,250,213	0	0	0	49,040	1,379,929
Maximum	2,623	8,745	2,122,523	24,036	2,673,623	199,834	31,613	8,409	2,466	572	160,835,134	278	14,349,676	433	345,225	8,273,869
SD	872	2,705	796,209	7,663	641,950	63,106	9,692	3,458	623	196	41,188,478	88	4,321,715	136	107,393	2,325,539
Total	5,841	17,371	5,461,683	87,480	15,018,080	815,760	42,760	17,074	8,936	1,083	603,718,930	278	24,406,639	721	1,812,911	43,805,757

0=Sampled, but none collected.
Wed Feb 13 11:51:17 MST 2002 ;Results; E Plant: brayton.projected ; Units: annual.prod.forg Pathname:
P:/Intake/Brayton/Brayton_Science/scodes/tables.output.projected01/E.annual.prod.forg.brayton.projected.csv

Table F3-10: Average Annual Impingement and Entrainment at Brayton Point
(sum of annual means of all species evaluated)

	Impingement	Entrainment
Raw losses (# of organisms)	44,752	16,703,221,011
Age 1 equivalents (# of fish)	69,329	3,847,045
Fishery yield (lb of fish)	5,091	70,410
Production foregone (lb of fish)	2,808	69,522,130

mixed.rollup.chap3.imp Wed Feb 13 13:28:53 MST 2002
P:/Intake/Brayton/Brayton_Science/scodes/tables.output.projected01/flowchart.chap3.IMP.csv
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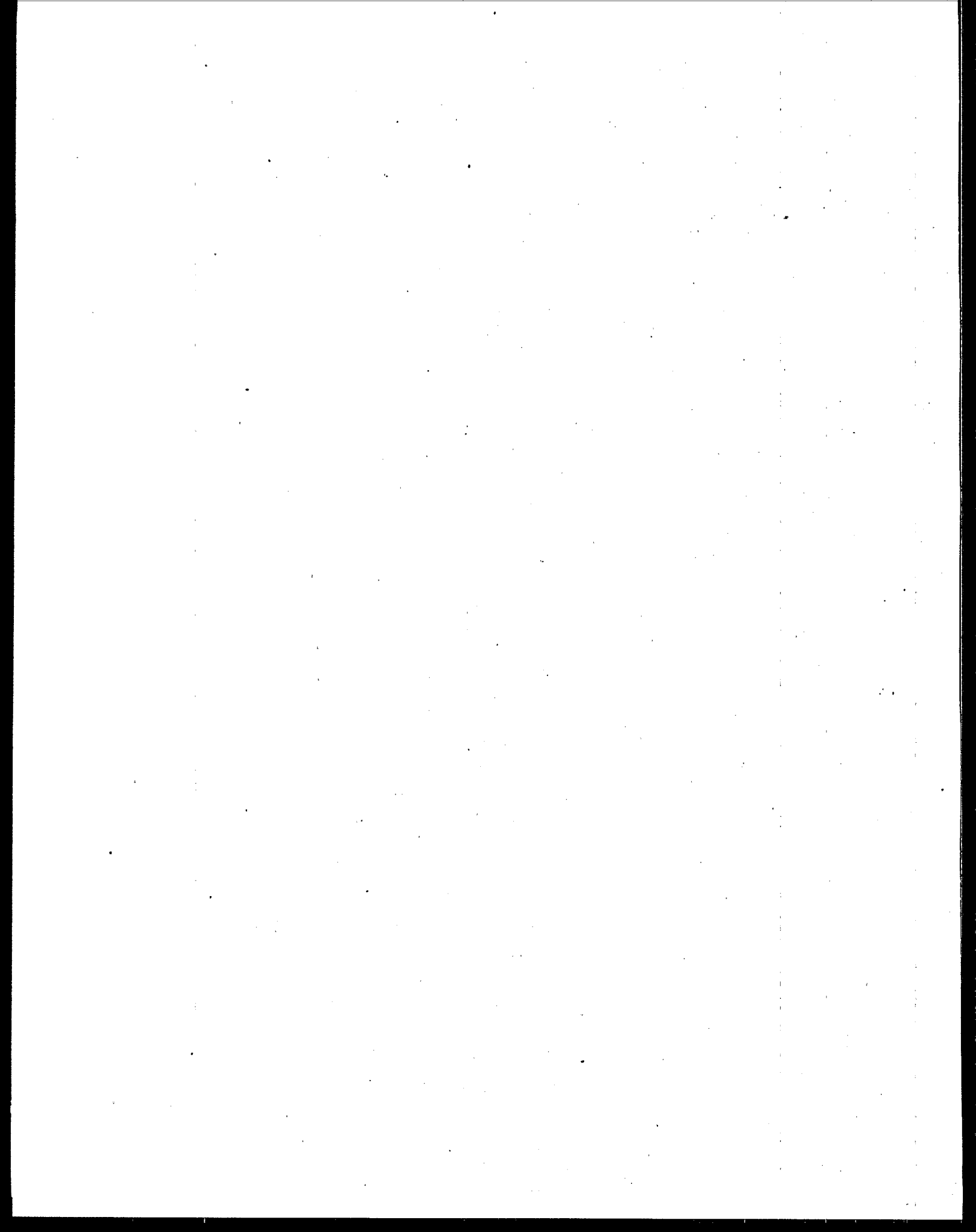
Chapter F4:

Value of I&E Losses at the Brayton Point Station Based on Benefits Transfer Techniques

This chapter presents the results of EPA's evaluation of the economic losses that are associated with I&E at the Brayton Point Station using benefits transfer techniques. Section F4-1 provides an overview of the valuation approach, Section F4-2 discusses the value of losses to recreational fisheries, Section F4-3 discusses the value of commercial fishery losses, Section F4-4 discusses values of forage losses, Section F4-5 discusses nonuse values, and Section F4-6 summarizes benefit transfer results.

F4-1 OVERVIEW OF VALUATION APPROACH

I&E at Brayton Point affect recreational and commercial fisheries as well as forage species that contribute to the biomass of fishery species. EPA evaluated all these species groups to capture the total economic impact of I&E at Brayton Point.

Recreational fishery impacts are based on benefits transfer methods, applying results from nonmarket valuation studies. Commercial fishery impacts are based on commodity prices for the individual species. The

economic value of forage species losses is determined by estimating the replacement cost of these fish if they were to be restocked with hatchery fish, and by considering the foregone biomass production of forage fish resulting from I&E losses and the consequential foregone production of commercial and recreational species that use the forage species as a prey base. All of these methods are explained in further detail in Chapters A5 and A9 of this document.

Many of the I&E-impacted fish species at Brayton Point are harvested both recreationally and commercially. To avoid double-counting the economic impacts of I&E on these species, EPA determined the proportion of total species landings attributable to recreational and commercial fishing, and applied this proportion to the impacted fishery catch. For example, if 30 percent of the landed numbers of one species are harvested commercially at a site, then 30 percent of the estimated catch of I&E-impacted fish are assigned to the increase in commercial landings. The remaining 70 percent of the estimated total landed number of I&E-impacted adult equivalents are assigned to the recreational landings.

The National Marine Fisheries Service (NMFS) provides both recreational and commercial fishery landings data by state. To determine what proportions of total landings per state occur in the recreational or commercial fishery, EPA summed the landings data for the recreational and commercial fishery, and then divided by each category to get the corresponding percentage. The percentages applied in this analysis are presented in Table F4-1.

Table F4-1: Percentages of Total Impacts in the Recreational and Commercial Fisheries of Selected Species at Brayton Point Station

Fish Species	Percent Impacts to Recreational Fishery	Percent Impacts to Commercial Fishery
Atlantic menhaden	0	100
Butterfish	0	100
Rainbow Smelt	0	100
Silver Hake	0	100
Tautog	83	17
Weakfish	95	5
White perch	20	80
Windowpane	0	100
Winter flounder	8	92
Scup	45	55

Wed Feb 13 13:11:19 MST 2002; TableA:Percentages of total impacts occurring to the commercial and recreational fisheries of selected species; Plant: brayton.projected; Pathname: P:/Intake/Brayton/Brayton_Science/scodes/tables.output.projected01/TableA.Perc.of total.impacts.brayton.projected.csv

As discussed in Chapter A5 of Part A of this document, the yield estimates in Chapter F3 represent the total pounds of foregone yield for both the commercial and recreational catch combined. For the economic valuation discussed in this chapter, Table F4-1 partitions total yield between commercial and recreational fisheries based on the landings in each fishery. Because the economic evaluation of recreational yield is based on numbers of fish rather than pounds, foregone recreational yield was converted to numbers of fish. This conversion was based on the average weight of harvestable fish of each species. Table F4-2 shows these conversions for the impingement data presented in Section F3-4 of Chapter F3 and Table F4-3 displays the conversions for entrainment data. Note that the numbers of foregone recreational fish harvested are typically lower than the numbers of age 1 equivalent losses, since the age of harvest of most fish is greater than age 1.

Table F4-2: Summary of Brayton Point's Mean Annual Impingement of Fishery Species

Species	Impingement Count (#)	Age 1 Equivalents (#)	Total Catch (#)	Total Yield (lb)	Commercial Catch (#)	Commercial Yield (lb)	Recreational Catch (#)	Recreational Yield (lb)
Atlantic menhaden	2,076	2,623	851	308	851	308	0	0
Butterfish	176	278	25	7	25	7	0	0
Rainbow smelt	870	1,278	20	2	20	2	0	0
Silver hake	4,900	5,773	848	2,196	848	2,196	0	0
Tautog	1,131	1,230	127	548	22	93	105	455
Weakfish	503	600	124	419	6	21	118	398
White perch	1,723	2,297	79	25	63	20	16	5
Windowpane	1,094	1,320	582	122	582	122	0	0
Winter flounder	9,048	13,601	867	1,465	798	1,347	69	117
Total	21,521	28,999	3,522	5,091	3,214	4,116	308	975

Table F4-3: Summary of Brayton Point's Mean Annual Entrainment of Fishery Species

Species	Entrainment Count (#)	Age 1 Equivalents (#)	Total Catch (#)	Total Yield (lb)	Commercial Catch (#)	Commercial Yield (lb)	Recreational Catch (#)	Recreational Yield (lb)
Atlantic menhaden	625,117,471	10,523	3,414	1,236	3,414	1,236	0	0
Rainbow smelt	3,340,371	49,506	766	56	766	56	0	0
Scup	2,851,071	509	46	54	25	29	21	24
Silver hake	43,450	2	0	1	0	1	0	0
Tautog	3,953,743,774	30,149	3,112	13,433	529	2,284	2,583	11,149
Weakfish	66,474,092	492	102	343	5	17	97	326
White perch	55,050	0	0	0	0	0	0	0
Windowpane	368,327,045	7,369	3,246	683	3,246	683	0	0
Winter flounder	795,883,100	507,114	32,331	54,605	29,745	50,237	2,587	4,368
Total	5,815,835,424	605,664	43,016	70,410	37,730	54,542	5,287	15,868

F4-2 ECONOMIC VALUE OF AVERAGE ANNUAL LOSSES TO RECREATIONAL FISHERIES RESULTING FROM I&E AT BRAYTON POINT STATION

F4-2.1 Economic Values of Recreational Fishery Losses from the Consumer Surplus Literature

There is a large literature that provides willingness-to-pay values for increases in recreational catch rates. These increases in value are benefits to the anglers, and are often referred to by economists as "consumer surplus." In applying this literature to value I&E impacts, EPA focused on changes in consumer surplus per additional fish caught.

When using values from the existing literature as proxies for the value of a trip or fish at a site not studied, it is important to select values for similar areas and species. Table F4-4 gives a summary of several studies that are closest to Mt. Hope Bay fisheries in geographic area and relevant species.

Table F4-4: Selected Valuation Studies for Estimating Changes in Catch Rates

Authors	Study Location and Year	Item Valued	Value Estimate ($2000)	
McConnell and Strand (1994)	Mid- and south Atlantic coast, anglers targeting specific species, 1988	Catch rate increase of 1 fish per trip, values used are for NY[a]	Small game fish Bottom fish Flatfish	$9.54 $2.54 $5.35
Hicks et al. (1999)	Mid-Atlantic coast, 1994	Catch rate increase of 1 fish per trip, from historical catch rates at all sites, weighted average of MA and RI	Small game fish Bottom fish Flatfish	$3.61 $2.40 $5.04
Agnello (1989)	Atlantic coast, 1981	Mean value per fish caught, for the Atlantic coast[b]	Weakfish	$2.72
Tudor et al. (2002)[c]	Delaware Estuary, 1994-98	Willingness to pay for an additional fish caught per trip	Bottom fish (weakfish) Small game fish (striped bass) Flatfish (flounder)	$11.50 $18.14 $3.92

[a] Value was reported as "two month value per angler for a half fish catch increase per trip." From 1996 National Survey of Fishing, Hunting and Wildlife-Associated Recreation (U.S. DOI, 1997), the average saltwater angler takes 1.5 trips in a 2 month period. Therefore, to convert to a "1 fish per trip" value EPA divided the 2 month value by 1.5 trips and then multiplied it by 2, assuming the value of a fish was linear.

[b] These values were reported as "consumer surplus for an 20 percent increase in catch rate for all fish." The average catch rate was 4.95 fish per trip, therefore a 20 percent increase in catch is equivalent to 1 more fish.

[c] Tudor et al. (2002) refers to this document; see Chapter B-5.

McConnell and Strand (1994) estimated fishery values for the mid- and south Atlantic states using data from the National Marine Fisheries Statistical Survey. They created a random utility model of fishing behavior for nine states, the northernmost being New York and the southernmost being eastern Florida. The New York values are used here, as they are the closest geographically to Brayton Point Station. In this model they specified four categories of fish: small gamefish (e.g., striped bass), flatfish (e.g., flounder), bottomfish (e.g., weakfish, spot, Atlantic croaker, perch), and big gamefish (e.g., shark). For each state and fish category, they estimated per angler values for access to marine waters and for an increase in catch rates.

Hicks et al. (1999) used the same methodology as McConnell and Strand (1994) but estimated values for a day of fishing and an increase in catch rates for the Atlantic states from Virginia north to Maine. Their estimates were generally lower than those of McConnell and Strand (1994) and may serve as a lower bound for the values of fish.

Agnello (1989) estimated one value for increased weakfish catch rates in all the Atlantic states. This study is useful because it values weakfish specifically, but the area considered ranges from Florida to Maine. This greater area may differ from Mount Hope Bay, where weakfish is a relatively important recreational species.

Tudor et al. (2002; See chapter B-5 of this document) applied a random utility model (RUM) to the recreational fishery impacts associated with I&E in the Delaware transitional estuary. The methods, data, and results of the Tudor et al. (2002; See chapter B-5 of this document) study are discussed in greater detail in Chapters A-10 and B-5 of this document. The willingness to pay (WTP) estimates derived by this study were not available at the time that the benefits transfer approach was applied to this case study, therefore the results developed below do not reflect these estimated values. However, the Tudor et al. (2002; See chapter B-5 of this document) values are consistent with – and for bottom fish and small game fish, somewhat higher than – the other values cited from the literature and used in this benefits transfer analysis. The Tudor et al. values will be included in subsequent updates of this case study analysis.

F4-2.2 Economic Values of Recreational Fishery Losses Resulting from I&E at Brayton Point Station

EPA estimated the average annual economic value of Brayton Point I&E impacts to recreational fisheries using the I&E estimates presented in Tables F4-2 and F4-3 and the economic values presented in Table F4-4. Since none of the studies in Table F4-4 consider fishing in Mount Hope Bay directly, EPA established a lower and upper value for each impacted recreational species to estimate a unit value for recreational landings. Results are displayed in Tables F4-5 and F4-6, for impingement and entrainment, respectively. The estimated total losses to the recreational fisheries range from $1,100 to $1,700 for impingement per year, and from $22,600 to $38,800 annually for entrainment.

Table F4-5: Average Annual Impingement of Recreational Fishery Species at Brayton Point Station and Associated Economic Values Based on the Impingement Data in Table F4-2

Species	Loss to Recreational Catch from Impingement (# of fish)	Recreational Value/Fish		Loss in Recreational Value from Impingement	
		Low	High	Low	High
Tautog	105	$3.61	$9.54	$380	$1,005
Weakfish	118	$2.40	$2.72	$289	$321
White perch	16	$2.40	$2.54	$38	$40
Winter flounder	69	$5.04	$5.35	$350	$371
Total	308			$1,056	$1,737

Wed Feb 13 13:11:28 MST 2002; TableB: recreational losses and value for selected species; Plant: brayton.projected; type: I Pathname: P:/Intake/Brayton/Brayton_Science/scodes/tables.output.projected01/TableB.rec.losses.brayton.projected.I.csv

Table F4-6: Average Annual Entrainment of Recreational Fishery Species at Brayton Point Station and Associated Economic Values Based on the Entrainment Data in Table F4-3

Species	Loss to Recreational Catch from Entrainment (number of fish)	Recreational Value/Fish		Annual Loss in Recreational Value from Entrainment ($2000)	
		Low	High	Low	High
Scup	20	$2.40	$2.54	$49	$52
Tautog	2,583	$3.61	$9.54	$9,313	$24,642
Weakfish	97	$2.40	$2.72	$237	$263
Winter flounder	2,586	$5.04	$5.35	$13,041	$13,838
Total	5,287			$22,641	$38,794

Wed Feb 13 13:11:34 MST 2002; TableB: recreational losses and value for selected species; Plant: brayton.projected; type: E
Pathname: P:/Intake/Brayton/Brayton_Science/scodes/tables.output.projected01/TableB.rec.losses.brayton.projected.E.csv

F4-3 ECONOMIC VALUE OF AVERAGE ANNUAL COMMERCIAL FISHERY LOSSES RESULTING FROM I&E AT BRAYTON POINT STATION

F4-3.1 Average Annual I&E Losses of Commercial Yield at Brayton Point and Economic Value of Losses

I&E losses to commercial catch (pounds) are presented in Tables F4-2 (for impingement) and F4-3 (for entrainment) based on the commercial and recreational splits listed in Table F4-1. EPA estimates of the economic value of these losses are displayed in Tables F4-7 and F4-8 for impingement and entrainment, respectively. Market values per pound are listed as well as the total market losses experienced by the commercial fishery. Values for commercial fishing are relatively straightforward because commercially caught fish are a commodity with a market price. The estimates of market loss to commercial fisheries are $2,700 for impingement per year, and $69,300 annually for entrainment.

Table F4-7: Average Annual Impingement of Commercial Fishery Species at Brayton Point Station and Associated Economic Values Based on the Impingement Data in Table F4-2

Species	Loss to Commercial Catch from Impingement (lb of fish)	Commercial Value (lb of fish)	Annual Loss in Commercial Value from Impingement ($2000)
Butterfish	7	$0.66	$5
Atlantic menhaden	308	$0.04	$14
Rainbow smelt	1	$0.19	$0
Silver hake	2,196	$0.33	$714
Tautog	93	$0.71	$66
Weakfish	21	$0.75	$16
White perch	20	$1.39	$28
Windowpane	122	$0.56	$68
Winter flounder	1,347	$1.34	$1,803
Total	4,116		$2,713

Wed Feb 13 13:11:29 MST 2002; TableC: commercial losses and value for selected species; Plant: brayton.projected; type: I
Pathname: P:/Intake/Brayton/Brayton_Science/scodes/tables.output.projected01/TableC.comm.losses.brayton.projected.I.csv

Table F4-8: Average Annual Entrainment of Commercial Fishery Species at Brayton Point Station and Associated Economic Values Based on the Entrainment Data in Table F4-3

Species	Loss to Commercial Catch from Entrainment (lb of fish)	Commercial Value (lb of fish)	Annual Loss in Commercial Value from Entrainment ($2000)
Atlantic menhaden	1,236	$0.04	$55
Rainbow smelt	56	$0.19	$11
Scup	29	$0.81	$24
Silver hake	1	$0.33	$0
Tautog	2,284	$0.71	$1,614
Weakfish	17	$0.75	$13
Windowpane	683	$0.56	$382
Winter flounder	50,237	$1.34	$67,222
Total	54,542		$69,321

Wed Feb 13 13:11:34 MST 2002; TableC: commercial losses and value for selected species; Plant: brayton.projected; type: E
Pathname: P:/Intake/Brayton/Brayton_Science/scodes/tables.output.projected01/TableC.comm.losses.brayton.projected.E.csv

F4-3.2 Economic Surplus Impacts of Commercial Landings Losses

EPA expressed changes to commercial activity thus far as changes from dockside market landings. However, to determine the total impact on economic surplus from changes to the commercial fishery, EPA determined the losses experienced by producers wholesalers, retailers, and consumers.

The total social benefits (economic surplus) are greater than the increase in dockside landings, because the increased landings by commercial fishermen contribute to economic surplus in each of a multi-tiered set of markets for commercial fish. The total economic surplus impact thus is valued by examining the multi-tiered markets through which the landed fish are sold, according to the methods and data detailed in Chapter A9.

The first step of the analysis involves a fishery-based assessment of I&E-related changes in commercial landings (pounds of commercial species as sold dockside by commercial harvesters). The results of this dockside landings value step are described above. The next steps then entail tracking the anticipated additional economic surplus generated as the landed fish pass from dockside transactions to other wholesalers, retailers and, ultimately, consumers. The resulting total economic surplus measures include producer surplus to the watermen who harvest the fish, as well as the rents and consumer surplus that accrue to buyers and sellers in the sequence of market transactions that apply in the commercial fishery context.

To estimate producer surplus from the landings values, EPA relied on empirical results from various researchers that can be used to infer producer surplus for watermen based on gross revenues (landings times wholesale price). The economic literature (Huppert, 1990; Rettig and McCarl, 1985) suggests that producer surplus values for commercial fishing ranges from 50 to 90 percent of the market value. In assessments of Great Lakes fisheries, an estimate of approximately 40% has been derived as the relationship between gross revenues and the surplus of commercial fishermen (Cleland and Bishop, 1984, Bishop, personal communication, 2002). For the purposes of this study, EPA believes producer surplus to watermen is probably in the range of 40% to 70% of dockside landings values.

Producer surplus is one portion of the total economic surplus impacted by increased commercial stocks — the total benefits are comprised of the economic surplus to producers, wholesalers, processors, retailers, and consumers. Primary empirical research deriving "multi-market" welfare measures for commercial fisheries have estimated that surplus accruing to commercial anglers amount to approximately 22% of the total surplus accruing to watermen, retailers and consumers combined (Norton et al., 1983; Holt and Bishop, 2002). Thus, total economic surplus across the relevant commercial fisheries multi-tiered markets can be estimated as approximately 4.5 times greater than producer surplus alone (given that producer surplus is roughly 22% of the total surplus generated). This relationship is applied in the case studies to estimate total surplus from the projected changes in commercial landings.

Applying this method, estimates of the economic loss to commercial fisheries resulting from I&E at Brayton Point Station ranges from $4,900 to $8,600 per year for impingement and from $126,000 to $220,600 per year for entrainment.

F4-4 ECONOMIC VALUE OF FORAGE FISH LOSSES

Many species affected by I&E are not commercially or recreationally fished. For the purposes in this study, EPA referred to these species as forage fish. Forage fish are species that are prey for other species and are important components of aquatic food webs. Table F4-9 summarizes impingement losses of forage species at Brayton Point Station and Table F4-10 summaries entrainment losses. The following sections discuss the economic valuation of these losses using two alternative valuation methods.

Table F4-9: Summary of Brayton Point's Mean Annual Impingement of Forage Species

Species	Impingement Count (#)	Age 1 Equivalents (#)	Production Forgone (lb)
Alewife	5,998	8,855	168
Atlantic silverside	4,784	9,113	2
Bay anchovy	3,350	6,090	1
Hogchoker	6,984	12,968	6
Striped killifish	418	572	4
Threespine stickleback	1,697	2,732	1
Total	23,231	40,330	181

Table F4-10: Summary of Brayton Point's Mean Annual Entrainment of Forage Species

Species	Entrainment Count (#)	Age 1 Equivalents (#)	Production Foregone (lb)
Alewife	1,076,500	460	584
American sand lance	84,520,243	453,236	1,737
Atlantic silverside	18,759,840	7,999	8,748
Bay anchovy	10,214,225,528	1,231,050	1,501,808
Hogchoker	106,615,903	34,148	81,576
Seaboard goby	462,170,823	1,513,836	894
Threespine stickleback	16,750	653	28
Total	10,887,385,587	3,241,381	1,595,375

Replacement cost of fish

The replacement value of fish can be used in several instances. First, if a fish kill of a fishery species is mitigated by stocking of hatchery fish, then losses to the commercial and recreational fisheries would be reduced, but fish replacement costs would still be incurred and should be accounted for. Second, if the fish are not caught in the commercial or recreational fishery, but are important as forage or bait, the replacement value can be used as a lower bound estimate of their value (it is a lower bound because it would not consider how reduction in their stock may affect other species' stocks). Third, where there are not enough data to allow calculation of value losses to the recreational and commercial fisheries, replacement cost can be used as a proxy for lost fishery values. Typically the consumer or producer surplus is greater than fish replacement costs, and replacement costs typically omit problems associated with restocking programs (e.g., limiting genetic diversity).

The cost of replacing forage fish lost to I&E has two main components. The first component is the cost of raising the replacement fish. Table F4-11 displays the replacement costs of two of the forage fish species known to be impinged or entrained at Brayton Point. The costs are average costs to fish hatcheries across North America to produce different species of fish for stocking. The second component of replacement cost is the transportation cost, which includes costs associated with vehicles, personnel, fuel, water, chemicals, containers, and nets. The AFS (1993) estimates these costs at approximately

$1.13 per mile, but does not indicate how many fish (or how many pounds of fish) are transported for this price. Lacking relevant data, EPA does not include the transportation costs in this valuation approach.

Table F4-11 also presents the computed values of the annual average forage replacement cost losses. The value of the losses of forage species using the replacement cost method is $400 per year for impingement and $17,900 per year for entrainment.

Table F4-11: Replacement Cost of Various Forage Fish Species at Brayton Point Station

Species	Hatchery Costs[a] ($/lb)	Annual Cost of Replacing Forage Losses ($2000)	
		Impingement	Entrainment
Alewife	0.34[b]	$133	$7
American sand lance	0.34[b]	$0	$591
Atlantic silverside	0.34[b]	$64	$56
Bay anchovy	$3.51	$79	$16,004
Hogchoker	0.34[b]	$50	$131
Seaboard goby	0.34[b]	$0	$1,055
Striped killifish	0.34[b]	$7	$0
Threespine stickleback	$2.58	$65	$15
Total		$398	$17,860

[a] Values are from AFS (1993). These values were inflated to 2000$ from 1989$, but this could be imprecise for current fish rearing and stocking costs.
[b] Individual species value is not available and thus an average of all species is used.

Wed Feb 13 13:11:29 MST 2002; TableD: loss in selected forage species; Plant: brayton.projected; type: I Pathname: P:/Intake/Brayton/Brayton_Science/scodes/tables.output.projected01/TableD.forage.eco.ter.repl.brayton.projected.I.csv

Production foregone value of forage fish .

This approach considers the foregone production of commercial and recreational fishery species resulting from I&E of forage species based on estimates of trophic transfer efficiency, as discussed in Chapter A5 of Part A of this document. The economic valuation of forage losses is based on the dollar value of the foregone fishery yield resulting from these losses. Results for impingement of forage species at Brayton Point range from $73 to $204, and results for entrainment range from $3,400 to $4,700 per year (Table F4-12). The values listed are obtained by converting the forage species into species that may be commercially or recreationally valued.

Table F4-12: Mean Annual Value of Production Foregone of Selected Fishery Species Resulting From Entrainment of Forage Species at Brayton Point Station Based on the Entrainment Data in Table F4-10

Species	Annual Loss in Production Foregone Value from Entrainment of Forage Species ($2000)	
	Low	High
Atlantic menhaden	$1	$1
Rainbow smelt	$19	$33
Scup	$3,149	$4,352
Silver hake	$13	$23
Tautog	$1	$2
Weakfish	$1	$1
Windowpane	$16	$27
Winter flounder	$182	$307
Total	$3,381	$4,747

Wed Feb 13 13:11:35 MST 2002; TableD: loss in selected forage species; Plant: brayton.projected; type: E Pathname: P:/Intake/Brayton/Brayton_Science/scodes/tables.output.projected01/TableD.forage.eco.ter.repl.brayton.projected.E.csv

F4-5 NONUSE VALUES

Recreational consumer surplus and commercial impacts are only part of the total losses that the public realizes from I&E impacts on fisheries. Nonuse or passive use impacts arise when individuals value environmental changes apart from any past, present, or anticipated future use of the resource in question. Such passive use values have been categorized in several ways in the economic literature, typically embracing the concepts of existence (stewardship) and bequest (intergenerational equity) motives. Using a "rule of thumb" that nonuse impacts are at least equivalent to 50 percent of the recreational use impact (see Chapter A9 for further discussion), EPA estimated nonuse values for baseline losses at Brayton to range from $500 to $900 per year for impingement and from $11,300 to $19,400 per year for entrainment.

F4-6 SUMMARY OF MEAN ANNUAL ECONOMIC VALUE OF I&E AT BRAYTON POINT STATION

Table F4-13 summarizes the economic values associated with mean annual I&E at Brayton Point Station. Total impacts range from $6,500 to $11,600 per year for impingement and from $163,400 to $296,600 per year for entrainment.

Table F4-13: Summary of Economic Valuation of Mean Annual I&E at Brayton Point Station ($2000)				
		Impingement	**Entrainment**	**Total**
Commercial: Total Surplus (Direct Use, Market)	Low	$4,934	$126,039	$130,973
	High	$8,634	$220,568	$229,202
Recreational (Direct Use, Nonmarket)	Low	$1,056	$22,641	$23,697
	High	$1,737	$38,794	$40,531
Nonuse (Passive Use, Nonmarket)	Low	$528	$11,320	$11,849
	High	$869	$19,397	$20,266
Forage (Indirect Use, Nonmarket)				
Production Foregone	Low	$73	$3,381	$3,381
	High	$204	$4,747	$4,747
Replacement		$398	$17,860	$18,257
Total (Com + Rec + Nonuse + Forage)[a]	Low	$6,591	$163,382	$169,899
	High	$11,637	$296,620	$308,257

[a] In calculating the total low values, the lower of the two forage valuation methods (production foregone and replacement) was used and to calculate the total high values, the higher of the two forage valuation methods was used.
Wed Feb 13 13:11:36 MST 2002; TableE.summary; Plant: brayton.projected; Pathname:
P:/Intake/Brayton/Brayton_Science/scodes/tables.output.projected01/TableE.summary.brayton.projected.csv
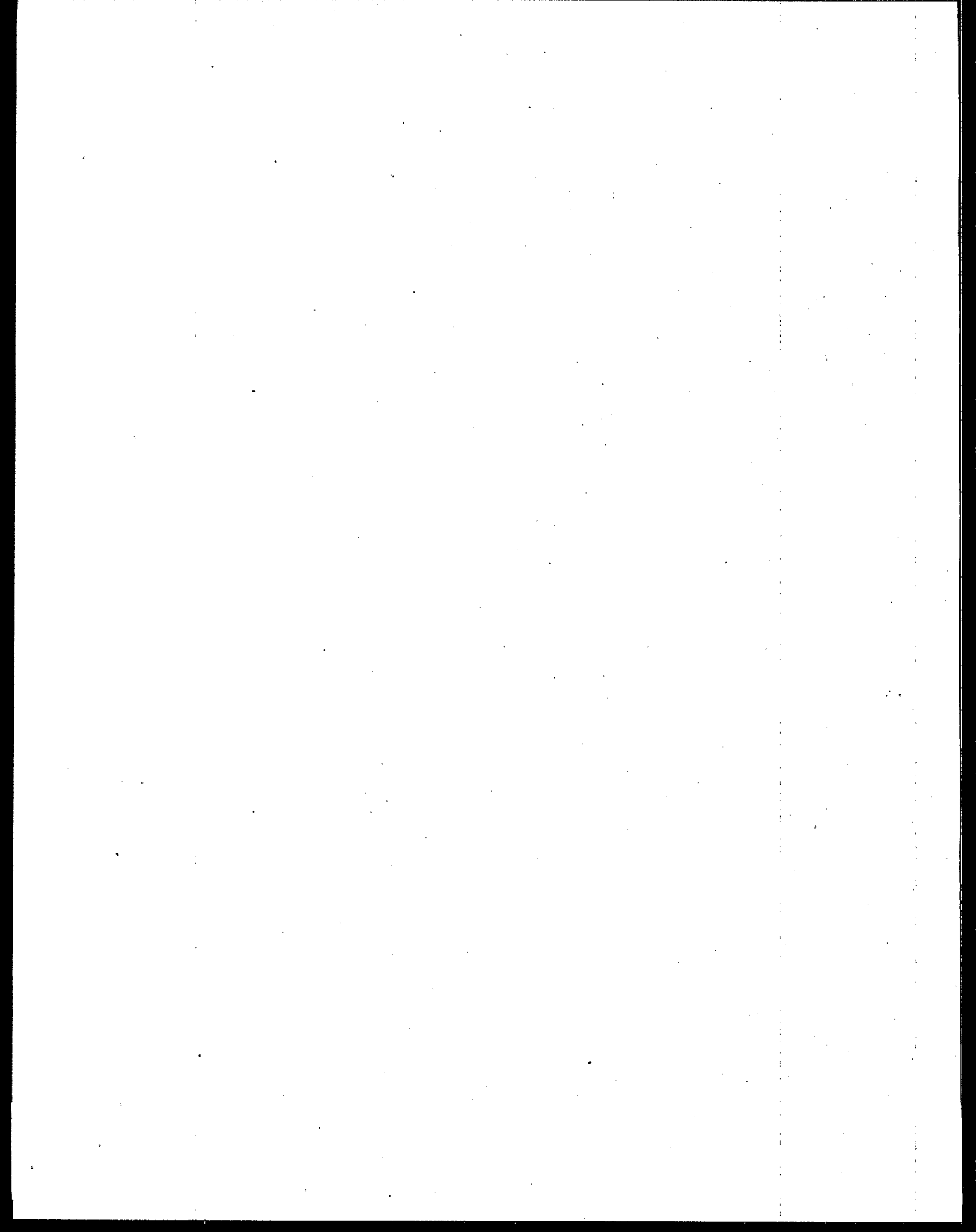
Chapter F5:
HRC Valuation of I&E Losses at
Brayton Point Station

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 Brayton Point Station (Brayton Point) cooling water intake structure. 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 the I&E losses at Brayton Point of $28.3 million, which is the cost of replacing the impinged and entrained organisms through the restoration of submerged aquatic vegetation (SAV), restoration of tidal wetlands, and installation of fish passageways and monitoring to quantify the productivity of these habitats (values to increase species production through construction of artificial reefs is not included in this value).

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 Brayton Point. 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 Brayton Point.

Cost-reducing assumptions are identified throughout this chapter and were incorporated extensively. Most significantly, the HRC valuation estimates for the I&E losses at Brayton Point 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 F5-1 through F5-8 present the information, methods, assumptions, and conclusions that were used to complete the HRC valuation of the I&E losses at Brayton Point following the eight steps described in Chapter A11 of Part A of this document. Section F5-8 also presents additional detail on the valuation of the I&E losses at Brayton Point, providing separate annualized valuation estimates for the aquatic organisms lost to impingement and for those lost to entrainment.

F5-1 STEP 1: QUANTIFY I&E LOSSES

Brayton Point 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 Brayton Point, including commercial, recreational, and forage fish species, based on information provided in facility I&E monitoring reports and detailed in Chapter F3.

Of those species, EPA incorporated the 18 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 Brayton Point for these 18 species from 1974 to 1983, adjusted for current operations, calculated by the EAM (see Chapter F3 for additional descriptions of source data and calculation of the age 1 equivalents) are presented in Table F5-1, in order of decreasing mean annual I&E losses (this information is also presented in Tables F3-3 and F3-7 for impingement and entrainment losses respectively).

Table F5-1: Mean Annual Age 1 Equivalent I&E Losses of Fishes at Brayton Point, 1974-1983 Adjusted for Current Operations			
Species	**Impingement**	**Entrainment**	**Total**
Seaboard goby	0	1,513,836	1,513,836
Bay anchovy	6,090	1,231,050	1,237,140
Winter flounder	13,601	507,114	520,715
American sand lance	0	453,236	453,236
Rainbow smelt	1,278	49,506	50,784
Hogchoker	12,968	34,148	47,116
Tautog	1,230	30,149	31,379
Atlantic silverside	9,113	7,999	17,112
Atlantic menhaden	2,623	10,523	13,146
Alewife	8,855	460	9,315
Windowpane	1,320	7,369	8,689
Silver hake	5,773	2	5,775
Threespine stickleback	2,732	653	3,385
White perch	2,297	0	2,297
Weakfish	600	492	1,092
Striped killifish	572	0	572
Scup	0	509	509
Butterfish	278	0	278
Total age 1 eq. losses	69,330	3,847,046	3,916,376

F5-2 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 F3, Section F3-2, 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 Brayton Point.

F5-3 Step 3: Identify Potential Habitat Restoration Alternatives to Offset I&E Losses

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

- ▶ 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 F5-1). 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 Brayton Point that use SAV beds during early life stages include Atlantic menhaden, tautog, and rainbow smelt (Laney, 1997).

Restore tidal wetlands

Tidal wetlands (Figure F5-2) 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, and threespine stickleback. Other migratory species that use tidal wetlands during their lives include the winter flounder and white perch (Dionne et al., 1999). Fish species that have been reported in restored salt ponds and tidal creeks include Atlantic menhaden, Atlantic silverside, and striped killifish (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 F5-1: Laboratory culture of eelgrass (Zostera marina)

Source: Boschker, 2001.

Figure F5-2: 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 F5-3), 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 F5-3: Salt marsh near Narragansett Bay, Rhode Island

Source: Save The Bay, 2001.

Create artificial reefs

Tautog, which are impinged and entrained at Brayton Point, use rocky or reef-like habitats with interstices that provide refuge from predators, especially during the night when the fish become torpid. These habitats can be created artificially with cobbles, concrete, and other suitable materials.

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 Brayton Point 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 F5-4). 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 F5-4: Example of a fish ladder at a hydroelectric dam
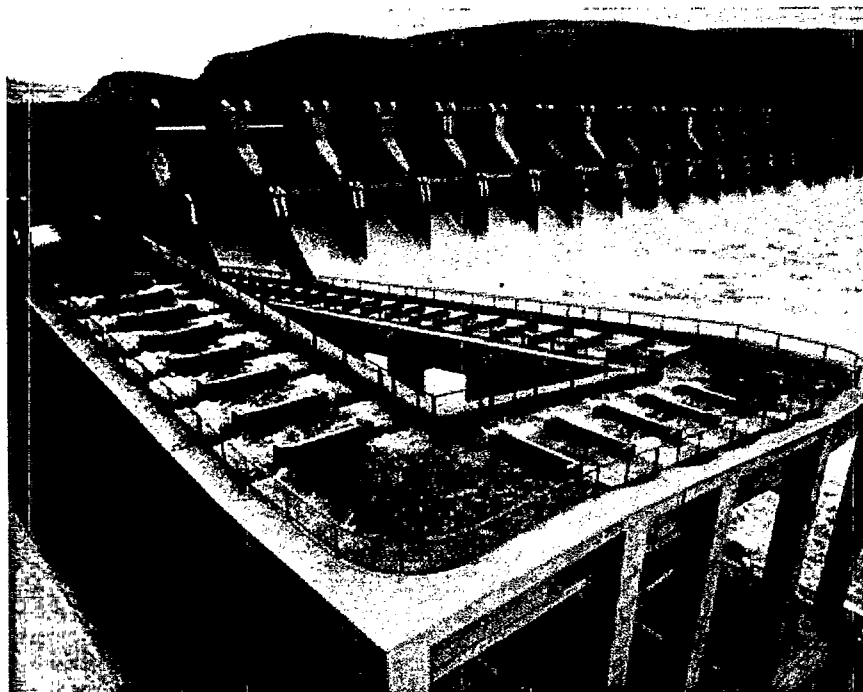
Source: Pollock, 2001.

F5-4 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 10, 2001 (Table F5-2), and through follow-up discussions that were held with numerous additional organizations (Table F5-3).

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 F5-4.

Table F5-2: Attendees at the Meeting on Habitat Prioritization for Species Impinged and Entrained at Brayton Point September 10, 2001, in Fall River, Massachusetts

Attendee	Organization
Anthony Chatwin	Conservation Law Foundation
Robert Lawton	Massachusetts Division of Marine Fisheries
Andrea Langhauser	Massachusetts Watershed Initiative — Ten Mile and Mount Hope Bay Watersheds
Kathi Rodrigues	National Marine Fisheries Service — Restoration Center
Chris Powell	Rhode Island Department of Environmental Management — Fish and Wildlife Division
Tom Ardito	Rhode Island Department of Environmental Management — Narragansett Bay Estuary Program
Andy Lipsky	Save the Bay
John Torgan	Save the Bay
Phil Colarusso	U.S. EPA Region I
John Nagle	U.S. EPA Region I

Table F5-3: 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)
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 F5-4: Preferred Restoration Alternatives Identified by Experts for Species Impinged and Entrained at Brayton Point

Species (age 1 eq. losses per year adjusted for current operations)	Selected Restoration Alternative
Threespine stickleback (3,385)	SAV restoration
Weakfish (1,092)	SAV restoration
Scup (509)	SAV restoration
Winter flounder (520,715)	Tidal wetlands restoration
Atlantic silverside (17,112)	Tidal wetlands restoration
Windowpane[a] (8,689)	Tidal wetlands restoration (improve habitat for prey)
Striped killifish (572)	Tidal wetlands restoration
Tautog (31,379)	Artificial reef creation
Rainbow smelt (50,784)	Anadromous fish passage (remove dams)
Alewife (9,315)	Anadromous fish passage
White perch (2,297)	Anadromous fish passage
Seaboard goby (1,513,836)	No habitat restoration/replacement alternative was identified.
American sand lance (453,236)	
Hogchoker (47,116)	
Silver hake (5,775)	
Bay anchovy (1,237,140)	No habitat restoration/replacement alternative was identified.
Atlantic menhaden (13,146)	
Butterfish (278)	

[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.

F5-5 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 F5-6) 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 F5-4. 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.

F5-5.1 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 F5-5 presents the fish species impinged or entrained at Brayton Point that would benefit most from SAV restoration, along with annual average I&E losses 1974-1983 adjusted for current operations, arranged by number of fish lost.

Table F5-5: Fish Species Impinged or Entrained at Brayton Point that Would Benefit Most from SAV Restoration

Species	Annual Average I&E Loss of Age 1 Equivalents (1974-1983 adjusted for current operations)	Percentage of Total I&E Losses for All Fish Species
Threespine stickleback	3,385	0.09%
Weakfish	1,092	0.03%
Scup	509	0.01%
Total	4,986	0.13%

F5-5.1.1 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 Brayton Point 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 F5-6 for species impinged and entrained at Brayton Point and identified as benefitting most from SAV restoration.

Table F5-6: Average Abundance in Buzzards Bay SAV (eelgrass) Habitats for Fish Species Impinged or Entrained at Brayton Point 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
Threespine stickleback	0.22	0.13
Weakfish[b]	no obs.	no obs.
Scup	0.32	1.03

[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] Weakfish were not among the species caught in more than 10 percent of the 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 Brayton Point and identified as benefitting most from SAV restoration are presented in Table F5-7.

Table F5-7: Average Abundance from Rhode Island SAV Sites for Brayton Point 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
Threespine stickleback	no obs.	19.67
Weakfish	no obs.	no obs.
Scup	0.17	0.69

[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 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 abundance values estimated from the sampling of the Fort Hill and Nauset Harbor SAV habitats for species impinged and entrained at Brayton Point and identified as benefitting most from SAV restoration are presented in Table F5-8.

Table F5-8: Average Abundance in Nauset Marsh Estuarine Complex SAV for Fish Species Impinged or Entrained at Brayton Point that Would Benefit Most from SAV Restoration

Species	Species Abundance (# fish per 100 m²)[a]	
	Fort Hill — High Density SAV	Nauset Harbor — High Density SAV
Threespine stickleback	5.92	47.08
Weakfish	no obs.	no obs.
Scup	no obs.	0.08

[a] High density habitats are defined as areas with eelgrass shoot densities > 100 per m² and shoot biomass (wet) > 100 g/m².
Source: Heck et al., 1989.

F5-5.1.2 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., 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 F5-9.

Table F5-9: Life Stage Adjustment Factors for Species Present at Brayton Point — 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
Threespine stickleback	juvenile	0.3077	juvenile	0.3077
Weakfish[a]	juvenile 2	0.3697	juvenile	0.3697
Scup	juvenile	0.0671	juvenile	0.0671

[a] Lifestage information was available for two juvenile stages of weakfish. Juvenile 2 represents the older of these two stages.

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.

F5-5.1.3 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 F5-10 presents the final estimates of the increase in age 1 production for two of the three Brayton Point species that benefit most from SAV restoration (weakfish were not sampled in any of the studies providing abundance estimates).

Table F5-10: Final Estimates of the Increase in Production of Age 1 Fish for Fish Species Impinged or Entrained at Brayton Point that Would Benefit Most from SAV Restoration

Species	Source of Initial Species Abundance Estimate	Species Abundance Estimate per 100 m² 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 m² of Restored SAV
Threespine stickleback	Heck et al. (1989) — Fort Hill	5.92	2.5	0.3077	1.0	4.55
	Heck et al. (1989) — Nauset Harbor	47.08	2.5	0.3077	1.0	36.21
	Hughes et al. (2000) — RI coastal ponds (high SAV)	19.67	2.5	0.3077	1.0	15.13
	Wyda et al. (in press) — Buzzards Bay (low SAV)	0.22	2.5	0.3077	1.0	0.17
	Wyda et al. (in press) — Buzzards Bay (high SAV)	0.13	2.5	0.3077	1.0	0.10
	Species average					11.23
Weakfish	Unknown					
Scup	Heck et al. (1989) — Nauset Harbor	0.08	2.5	0.0671	1.0	0.01
	Hughes et al. (2000) — RI coastal ponds (low SAV)	0.17	2.5	0.0671	1.0	0.03
	Hughes et al. (2000) — RI coastal ponds (high SAV)	0.69	2.5	0.0671	1.0	0.12
	Wyda et al. (in press) — Buzzards Bay (low SAV)	0.32	2.5	0.0671	1.0	0.05
	Wyda et al. (in press) — Buzzards Bay (high SAV)	1.03	2.5	0.0671	1.0	0.17
	Species average					0.08

F5-5.2 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 F5-11 identifies the I&E losses for fish species at Brayton Point that would benefit most from tidal wetland restoration, along with average I&E losses for 1974-1983 adjusted for current operations, arranged by number of fish lost.

Table F5-11: Fish Species Impinged or Entrained at Brayton Point that Would Benefit Most from Tidal Wetland Restoration

Species	Annual Average I&E Loss of Age 1 Equivalents (1974-1983 adjusted for current operations)	Percentage of Total I&E Losses across all Fish Species
Winter flounder	520,715	13.30%
Atlantic silverside	17,112	0.44%
Striped killifish	572	0.01%
Total	538,399	13.75%

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.

F5-5.2.1 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 Brayton Point 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 F5-12).

Table F5-12: Abundance Estimates from the Unrestricted Tidal Wetlands at Sachuest for Fish Species Impinged or Entrained at Brayton Point 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
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.
Striped killifish	throw trap	0.70	0.17	0.55
	lift net	no sampling	0.01	0.01

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

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.

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 F5-13 for the species impinged and entrained at Brayton Point and identified as benefitting most from tidal wetlands restoration.

Table F5-13: Abundance Estimates from the Unrestricted Tidal Wetlands at Galilee for Fish Species Impinged or Entrained at Brayton Point 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
Winter flounder	throw trap	no obs.	no obs.	no obs.
Atlantic silverside	throw trap	4.78	1.73	14.38
Striped killifish	throw trap	4.35	3.50	12.40

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 F5-14 for the species impinged and entrained at Brayton Point and identified as benefitting most from tidal wetlands restoration.

Table F5-14: Abundance Estimates from the Unrestricted Tidal Wetlands at Coggeshall for Fish Species Impinged or Entrained at Brayton Point that Would Benefit Most from Tidal Wetland Restoration

Species	Sampling Technique	Fish Density Estimates in Tidal Wetlands (fish per m²)	
		July 2000	September 2000
Winter flounder	throw trap	0.10	0.10
Atlantic silverside	throw trap	0.17	0.07
Striped killifish	throw trap	2.40	0.53

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 F5-15 for samples taken from 1990 through 2000.

Table F5-15: 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 m²)	
		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 F5-16 (personal communication, J. Temple, Rhode Island Division of Fish and Wildlife, 2002).

Table F5-16: 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 m²)		
		Narrow River	Winnapaug Pond	Point Judith Pond
Winter flounder	beach seine	0.32	0.21	0.21

F5-5.2.2 Adjusting tidal wetland sampling results to estimate annual average increase in production of age 1 fish

The sampling abundance results presented in Section F5-5.2.1 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 Brayton Point.

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 F5-5.2.1 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 F5-5.2.1 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 F5-17.

Table F5-17: Life Stage Adjustment Factors for Brayton Point Species — Tidal Wetland Restoration

Species	Oldest Life Stage before Age 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
Winter flounder	juvenile	0.1697	juvenile	0.1697
Atlantic silverside	juvenile	0.1347	juvenile	0.1347
Striped killifish	larvae	0.2107	juvenile	0.6054

As noted in Table F5-17, there are no juvenile to age 1 survival rate estimates used in the EAM for striped killifish. 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 F5-17 to convert densities of juveniles in SAV habitat to densities of age 1 individuals, as a cost minimizing assumption.

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 F5-18 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 F5-18: 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

F5-5.2.3 Final estimates of annual average age 1 fish production from tidal wetland restoration

Table F5-19 presents the final estimates of annual increased production of age 1 fish resulting from tidal wetland restoration for species impinged and entrained at Brayton Point and identified as benefitting most from tidal wetland restoration.

Table F5-19: 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 Brayton Point 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 m² 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 m² of Restored Tidal Wetland[bc]
Winter flounder	Raposa pers comm 2001	NERR — Prudence Isl. Coggeshall - July 2000	0.10	1.6	0.1697	1	19.23	0.00
	Raposa pers comm 2001	NERR — Prudence Isl. Coggeshall — Sept. 2000	0.10	1.6	0.1697	1	19.23	0.00
	C Powell pers comm 2001	Chepiwanoxet average 1990-2000 (seine)	0.09	2.0	0.1697	1	1.00	0.03
	C Powell pers comm 2001	Wickford average 1990-2000 (seine)	0.20	2.0	0.1697	1	1.00	0.07
	J. Temple pers comm 2002	Narrow River average 1998-2001 (seine)	0.32	2.0	0.1697	1	1.00	0.11
	J. Temple pers comm 2002	Winnapaug Pond average 1998-2001 (seine)	0.21	2.0	0.1697	1	1.00	0.07
	J. Temple pers comm 2002	Point Judith Pond average 1998-2001 (seine)	0.21	2.0	0.1697	1	1.00	0.07
	Species average							0.05
Atlantic silverside	Roman et al., submitted 2000 to *Restoration Ecology*	Sachuest Point — 1997	1.23	1.6	0.1347	1	18.18	0.01
	Roman et al., submitted 2000 to *Restoration Ecology*	Sachuest Point — 1998	0.20	1.6	0.1347	1	18.18	0.00
	Roman et al., submitted 2000 to *Restoration Ecology*	Sachuest Point — 1999	0.07	1.6	0.1347	1	18.18	0.00
	Raposa pers comm 2001	NERR — Prudence Isl. Coggeshall - July 2000	0.17	1.6	0.1347	1	19.23	0.00
	Raposa pers comm 2001	NERR — Prudence Isl. Coggeshall — Sept. 2000	0.07	1.6	0.1347	1	19.23	0.00
	Raposa, in press	Galilee Marsh — 1997	4.78	1.6	0.1347	1	11.90	0.09

Table F5-19: 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 Brayton Point 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 m² 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 m² of Restored Tidal Wetland[b]
Atlantic silverside	Raposa, in press	Galilee Marsh — 1998	1.73	1.6	0.1347	1	11.90	0.03
	Raposa, in press	Galilee Marsh — 1999	14.38	1.6	0.1347	1	11.90	0.26
	Species average							**0.05**
Striped killifish	Roman et al., submitted 2000 to *Restoration Ecology*	Sachuest Point — 1997	0.70	1.6	0.6054	1	18.18	0.04
	Roman et al., submitted 2000 to *Restoration Ecology*	Sachuest Point — 1998	0.17	1.6	0.6054	1	18.18	0.01
	Roman et al., submitted 2000 to *Restoration Ecology*	Sachuest Point — 1999	0.55	1.6	0.6054	1	18.18	0.03
	Roman et al., submitted 2000 to *Restoration Ecology*	Sachuest Point — 1998 (lift net)	0.01	1.3	0.6054	1	1.00	0.01
	Roman et al., submitted 2000 to *Restoration Ecology*	Sachuest Point — 1999 (lift net)	0.01	1.3	0.6054	1	1.00	0.01
	Raposa pers comm 2001	NERR — Prudence Isl. Coggeshall — July 2000	2.40	1.6	0.6054	1	19.23	0.12
Striped killifish	Raposa pers comm 2001	NERR — Prudence Isl. Coggeshall — Sept. 2000	0.53	1.6	0.6054	1	19.23	0.03
	Raposa, in press	Galilee Marsh — 1997	4.35	1.6	0.6054	1	11.90	0.35
	Raposa, in press	Galilee Marsh — 1998	3.50	1.6	0.6054	1	11.90	0.28

Table F5-19: 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 Brayton Point 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 m² 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 m² of Restored Tidal Wetland[b]
Striped killifish	Raposa, in press	Galilee Marsh — 1999	12.40	1.6	0.6054	1	11.90	1.01
Species average								0.19

[a] Sampling results are based on collections using 1 m² 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 m² so do not appear in the rounding of results for purposes of presentation.

F5-5.3 Estimates of Increased Age 1 Fish Production from Artificial Reef Development

Constructing reefs of cobbles or small boulders was the preferred restoration alternative for tautog because they generally favor habitats with interstices that provide forage and shelter from predators. Information for tautog on the annual average I&E losses for the period 1974-1983 adjusted for current operations at Brayton Point is presented in Table F5-20.

Table F5-20: Species with Quantified Age 1 Equivalent I&E Losses at Brayton Point that Would Benefit Most from Artificial Reef Development

Species	Annual Average I&E Loss of Age 1 Equivalents (1974-1983 adjusted for current operations)	Percentage of Total I&E Losses across All Fish Species
Tautog	31,379	0.80%
Total	31,379	0.80%

EPA could not find any studies that provided direct estimates of increased tautog production resulting from artificial reef development. Therefore, EPA used available tautog 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.

F5-5.3.1 Species abundance estimates in artificial reef habitats

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 F5-21.

Table F5-21: 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

F5-5.3.2 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).

Conversion to the age 1 equivalent life stage

The information used to develop life stage adjustment factors for juvenile tautog to age 1 equivalents is presented in Table F5-22.

Table F5-22: Life Stage Adjustment Factors for Brayton Point Tautog — 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
Tautog	juvenile	0.0131	juvenile	0.0131

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 tautog and/or that significant delays in the use of artificial reefs follows their emplacement. To the extent lower levels of tautog use or delays in such use do occur with artificial reefs, incorporating an adjustment factor of 1.0 represents a cost-reducing assumption.

F5-5.3.3 Final estimates of increases in age 1 production for artificial reefs

Table F5-23 presents the final estimates of annual increased production of age 1 equivalent tautog, based on the average across all sampling efforts, that would result from artificial reef emplacement.

Table F5-23: Final Estimates of Annual Increased Production of Age 1 Equivalent Tautog per Square Meter of Artificial Reef Developed

Species	Source of Initial Species Density Estimate	Species Abundance Estimates (fish/m² reef)	Sampling Efficiency Adjustment Factor	Life Stage Adjustment Factor	Restored vs. Undisturbed Habitat Adjustment Factor	Expected Age 1 Increased Production (fish per m² artificial reef)
Tautog	RI juvenile finfish survey, 1990-2000: Patience Island	0.028	2.0	0.0131	1.0	0.001
	RI juvenile finfish survey, 1990-2000: Spar Island	0.031	2.0	0.0131	1.0	0.001
	Species average					**0.001**

F5-5.4 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 Brayton Point that would benefit most from fish passageways are presented in Table F5-24, along with information on their annual average I&E losses for the period 1974-1983 adjusted for current operations.

Table F5-24: Anadromous Fish Species Impinged or Entrained at Brayton Point that Would Benefit Most from Fish Passageways

Species	Annual Average I&E Loss of Age 1 Equivalents (1974-1983 adjusted for current operations)	Percentage of Total I&E Losses across All Fish Species
Rainbow smelt	50,784	1.30%
Alewife	9,315	0.24%
White perch	2,297	0.06%
Total	62,396	1.59%

F5-5.4.1 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 F5-25.

Table F5-25: 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).

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.

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.

F5-5.4.2 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.

F5-5.4.3 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 F5-26 in providing final estimates of the expected increase in production of age 1 equivalent fish for anadromous species that are impinged or entrained at Brayton Point and that would benefit most from installation of fish passageways.

Table F5-26 Estimates of Increased Age 1 Fish for Fish Species Impinged or Entrained at Brayton Point 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
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.

F5-5.5 Estimates of Remaining Losses in Age 1 Fish Production from Species Without an Identified Habitat Restoration Alternative

Some species lost to I&E at Brayton Point 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 Brayton Point that fall into this category are listed in Table F5-27, along with their annual average I&E losses for 1974-1983 adjusted for current operations.

Table F5-27: Species Impinged or Entrained at Brayton Point that Lack a Habitat Restoration Alternative

Species	Average Annual I&E Loss of Age 1 Equivalent Organisms (1974-1983 adjusted for current operations)	Percentage of Total I&E Losses for All Finfish or Shellfish Species
Seaboard goby	1,513,836	38.65%
Bay anchovy	1,237,140	31.59%
American sand lance	453,236	11.57%
Hogchoker	47,116	1.20%
Atlantic menhaden	13,146	0.34%
Windowpane	8,689	0.22%
Silver hake	5,775	0.15%
Butterfish	278	0.01%
Total	**3,279,216**	**83.73%**

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 for these species through habitat restoration alternatives.

F5-6 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.

F5-6.1 Submerged Aquatic Vegetation Scaling

The information used to scale SAV restoration is presented in Table F5-28.

Table F5-28: Scaling of SAV Restoration Species Impinged or Entrained at Brayton Point

Species	Annual Average I&E Loss of Age 1 Equivalents (1974-1983 adjusted for current operations)	Best Estimate of Increased Production of Age 1 Fish per 100 m² of Revegetated Substrate (rounded)	Number of 100 m² Units of Revegetated SAV Required to Offset Estimated Average Annual I&E Loss
Scup	509	0.08	6,638
Threespine stickleback	3,385	11.23	301
Weakfish	1,092	Unknown	Unknown
Assumed units of implementation required to offset I&E losses for all of these species			**6,638**

F5-6.2 Tidal Wetlands Scaling

The information used to scale tidal wetland restoration is presented in Table F5-29.

Table F5-29: Scaling of Tidal Wetland Restoration for Species Impinged or Entrained at Brayton Point

Species	Annual Average I&E Loss of Age 1 Equivalents (1974-1983 adjusted for current operations)	Best Estimate of Increased Production of Age 1 Fish per m² of Restored Tidal Wetland (rounded)	Number of m² Units of Restored Tidal Wetland Required to Offset Estimated Average Annual I&E loss[a]
Winter flounder	520,715.	0.05	10,274,236
Atlantic silverside	17,112	0.05	343,237
Striped killifish	572	0.19	3,031
Assumed units of implementation required to offset I&E losses for all of these species			**10,274,236**

[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.

F5-6.3 Reef Scaling

The information used to scale artificial reef development is presented in Table F5-30. As expected, the very low productivity estimate for tautog derived in Section F5-5.3 translates to enormous artificial reef construction needs to offset I&E losses from a single species comprising only 0.8 percent of total I&E losses at Brayton Point. This result may be correct, but further investigation of potential tautog productivity at reefs is warranted.

Table F5-30: Scaling of Artificial Reef Development for Species Impinged or Entrained at Brayton Point

Species	Annual Average I&E Loss of Age 1 Equivalents (1974-1983 adjusted for current operations)	Best Estimate of Increased Production of Age 1 Fish per m² of Artificial Reef (rounded)	Number of m² Units of Artificial Reef Surface Habitat Required to Offset Estimated Average Annual I&E Loss
Tautog	31,379	0.001	40,915,621
Assumed units of implementation required to offset I&E losses for all of these species			**40,915,621**

F5-6.4 Anadromous Fish Passage Scaling

The information used to scale fish passageway installation is presented in Table F5-31.

Table F5-31: Scaling of Anadromous Fish Passageways for Species Impinged or Entrained at Brayton Point

Species	Annual Average I&E Loss of Age 1 Equivalents (1974-1983 adjusted for current operations)	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	9,315	8,892	1.05
Rainbow smelt	50,784	Unknown	Unvalued
White perch	2,297	Unknown	Unvalued
Assumed units of implementation required to offset I&E losses for all of these species			**1.00**

F5-7 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).

F5-7.1 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.

F5-7.1.1 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 m², 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 m² TERFS / 4,047 m² per acre) and 1:34 (120 1 m² TERFS / 4,047 m² 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 F5-32 presents the components of implementation unit cost for SAV restoration, incorporating this adjustment ratio in the last step.

Table F5-32: Implementation Unit Costs for SAV Restoration		
Expense Category	Cost per m² of SAV Restored	Cost per 100 m² 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

F5-7.1.2 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 F5-33.

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[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.

Table F5-33: Estimated Annual Unit Costs for a SAV Restoration Monitoring Program

Expense Category	Quantity	Daily Rate	Total Cost
Annual Expenditures			
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 m² restored habitat			$787
Annualized monitoring cost per 100 m² restored habitat			$557

F5-7.1.3 Total submerged aquatic vegetation restoration costs

Combining the annualized unit costs for implementation and monitoring, the total annualized cost for a 100 m² unit of SAV restoration is $1,234 (rounded to the nearest dollar).

F5-7.2 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.

F5-7.2.1 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, 2001a) 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 F5-34 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 F5-35, where the projects are organized by acres of *Phragmites* at the site, not the current tidal restriction.

Combined, Tables F5-34 and F5-35 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 F5-36 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 F5-34: 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 F5-35: Average per Acre Cost of Restoring *Phragmites* in Buzzards Bay Restricted Tidal Wetlands, by Size Class of Site

Phragmites Acres	Number of Sites	Cumulative Acreage	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 F5-36: 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

F5-7.2.2 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 F5-37.

Table F5-37: 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.

F5-7.2.3 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.

F5-7.3 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).

F5-7.3.1 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 F5-38 (personal communication, J. Catena, NOAA Restoration Center, 2001).

Table F5-38: 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.

F5-7.3.2 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.

F5-7.3.3 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.

F5-7.4 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.

F5-7.4.1 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.

F5-7.4.2 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).

F5-7.4.3 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).

F5-8 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 Brayton Point 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 Brayton Point losses (i.e., multiple restoration programs were required to benefit the diverse species lost at Brayton Point).

The total HRC estimates for Brayton Point are provided in Table F5-39, 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. Because of the sensitivity of these results to the inclusion/exclusion of the tautog-artificial reef results, total HRC estimates are presented for both scenarios.

Table F5-39: Total HRC Estimates for Brayton Point I&E Losses

Preferred Restoration Alternative	Species Benefitting from the Restoration Alternative		Required Units of Restoration Implementation[a]	Units of Measure for Preferred Restoration Alternative	Total Annualized Unit Cost	Total Annualized Cost
	Species	Average Annual I&E Loss of Age 1 Equivalents				
Restore SAV	Scup	509	**6,638**	100 m² of directly revegetated substrate	$1,233.50	$8,187,978
	Threespine stickleback	3,385	301			
	Weakfish	1,092	Unknown			
Restore tidal wetland	Winter flounder	520,715	**10,274,236**	m² of restored tidal wetland	$1.95	$20,069,076
	Atlantic silverside	17,112	343,247			
	Striped killifish	572	3,031			
Create artificial reefs	Tautog	31,379	**40,915,621**	m² of reef surface area	$24.85	$1,016,911,890
Install fish passageways	Alewife	9,315	**1.00**	New fish passageway	$49,438	$49,438[b]
	Rainbow smelt	50,784	Unknown			
	White perch	2,297	Unknown			
Species not valued	Seaboard goby	1,513,836	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
	Bay anchovy	1,237,140				
	American sand lance	453,236				
	Hogchoker	47,116				
	Atlantic menhaden	13,146				
	Windowpane	8,689				
	Silver hake	5,775				
	Butterfish	278				
Total annualized HRC valuation						$1,045,218,361
Total annualized HRC valuation excluding Tautog-artificial reefs						$28,306,491

[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.

To facilitate comparisons with the costs of alternative control technologies that could be considered to reduce I&E losses at Brayton Point, the combined I&E losses are broken down with separate values developed for the losses to impingement and entrainment (Tables F5-40 and F5-41 respectively).

A result of interest from Tables F5-40 and F5-41 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 ($28.6 million versus $28.3 million - excluding the tautog artificial reef results in both cases). 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 SAV restoration in Tables F5-40 and F5-41, 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 Brayton Point is presented in Figure F5-5.

Table F5-40: Total HRC Estimates for Impingement Losses at Brayton Point					
Preferred Restoration Alternative	**Species Benefitting from the Restoration Alternative**		**Required Units of Restoration Implementation[a]**	**Units of Measure for Preferred Restoration Alternative**	**Total Annualized Unit Cost**	**Total Annualized Cost**
	Species	**Average Annual I&E Loss of Age 1 Equivalents**				
Restore SAV	Threespine stickleback Scup Weakfish	2,732 0 600	**243** 0 Unknown	100 m² of directly revegetated substrate	$1,233.50	$299,741
Restore tidal wetland	Winter flounder Atlantic silverside Striped killifish	13,601 9,113 572	**268,362** 182,796 3,031	m² of restored tidal wetland	$1.95	$524,202
Create artificial reefs	Tautog	1,230	**1,603,818**	m² of reef surface area	$24.85	$39,861,098
Install fish passageways	Alewife White perch Rainbow smelt	8,855 2,297 1,278	**1.00** Unknown Unknown	New fish passageway	$49,438	$49,438[b]
Species not valued	Hogchoker Bay anchovy Silver hake Atlantic menhaden Windowpane Butterfish Seaboard goby American sand lance	12,968 6,090 5,773 2,623 1,320 278 0 0	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
Total annualized HRC valuation						$40,734,479
Total annualized HRC valuation excluding Tautog-artificial reefs						$873,381

[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.

Table F5-41: Total HRC Estimates for Entrainment Losses at Brayton Point

Preferred Restoration Alternative	Species Benefitting from the Restoration Alternative		Required Units of Restoration Implementation[a]	Units of Measure for Preferred Restoration Alternative	Total Annualized Unit Cost	Total Annualized Cost
	Species	Average Annual I&E Loss of Age 1 Equivalents				
Restore SAV	Scup Threespine stickleback Weakfish	509 653 492	**6,638** 58 Unknown	100 m² of directly revegetated substrate	$1,233.50	$8,187,978
Restore tidal wetland	Winter flounder Atlantic silverside Striped killifish	507,144 7,999 0.	**10,005,874** 160,451 0	m² of restored tidal wetland	$1.95	$19,544,873
Create artificial reefs	Tautog	30,149	**39,311,802**	m² of reef surface area	$24.85	$977,050,767
Install fish passageways	Alewife Rainbow smelt White perch	460 49,506 0	**0.00** Unknown Unknown	New fish passageway	$49,438	$0[b]
Species not valued	Seaboard goby Bay anchovy American sand lance Hogchoker Atlantic menhaden Windowpane Silver hake Butterfish	1,513,836 1,231,050 453,236 34,148 10,523 7,369 2 0	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
Total annualized HRC valuation						$1,004,783,618
Total annualized HRC valuation excluding Tautog-artificial reefs						$27,732,851

[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.

Figure F5-5: I&E Overview: Brayton Point Habitat-Based Replacement Costs (annualized cost results)

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┌─────────────────────────────────────────────────────────┐
│ 1. Age 1 equivalents losses per year                     │
│    I: 69,000 fish                                        │
│    E: 3.8 million fish                                   │
└─────────────────────────────────────────────────────────┘

┌───────────────────────────────────┐   ┌───────────────────────────────────┐
│ 2. Tidal wetland restoration costs │   │ 2. SAV costs                      │
│    I: winter flounder $0.5M/yr     │   │    I: threespine stickleback      │
│    E: winter flounder $19.5M/yr    │   │       $0.3M/yr                    │
│    I&E: winter flounder $20.1M/yr  │   │    E: scup $8.2M/yr               │
│                                    │   │    I&E: scup $8.2M/yr             │
└───────────────────────────────────┘   └───────────────────────────────────┘

┌───────────────────────────────────┐   ┌───────────────────────────────────┐
│ 2. Artificial reef costs           │   │ 2. Fish passage costs             │
│    I: tautog $39.9M/yr             │   │    I: alewife $49k/yr             │
│    E: tautog $977M/yr              │   │    E: alewife unvalued            │
│    I&E: tautog $1,017M/yr          │   │    I&E: alewife $49k/yr           │
└───────────────────────────────────┘   └───────────────────────────────────┘

        ┌───────────────────────────────────────────────────────┐
        │ 2. Species for which HRC values not calculated         │
        │    I: 6 fish species unvalued (29,000 lost per year)   │
        │    E: 7 fish species unvalued (3.3 million lost per year)│
        │    I&E: 8 fish species unvalued (3.3 million lost per year)│
        └───────────────────────────────────────────────────────┘

        ┌───────────────────────────────────────────────────────┐
        │ 3. Total HRC excluding tautog-artificial reefs         │
        │    (tidal wetlands + SAV + fish passage)               │
        │    I: $0.9M per year                                   │
        │    E: $27.7M/yr                                        │
        │    I&E: $28.3M/yr                                      │
        └───────────────────────────────────────────────────────┘
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F5-9 CONCLUSIONS

HRC analyses indicate that the cost of replacing organisms lost to I&E at the Brayton Point CWIS through habitat replacement is at least $28.3 million, in terms of annualized costs, when the tautog-artificial reef losses are excluded (see note on the tautog habitat productivity uncertainty in Section F5-5.6). This value is significantly greater than the maximum annual value of $0.3 million for Brayton Point 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 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 Brayton Point. In particular, annual losses of 3.3 million fish comprising 8 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 Brayton Point 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 Brayton Point CWIS is probably greater, and possibly much greater, than the current annualized estimate of $28.3 million.
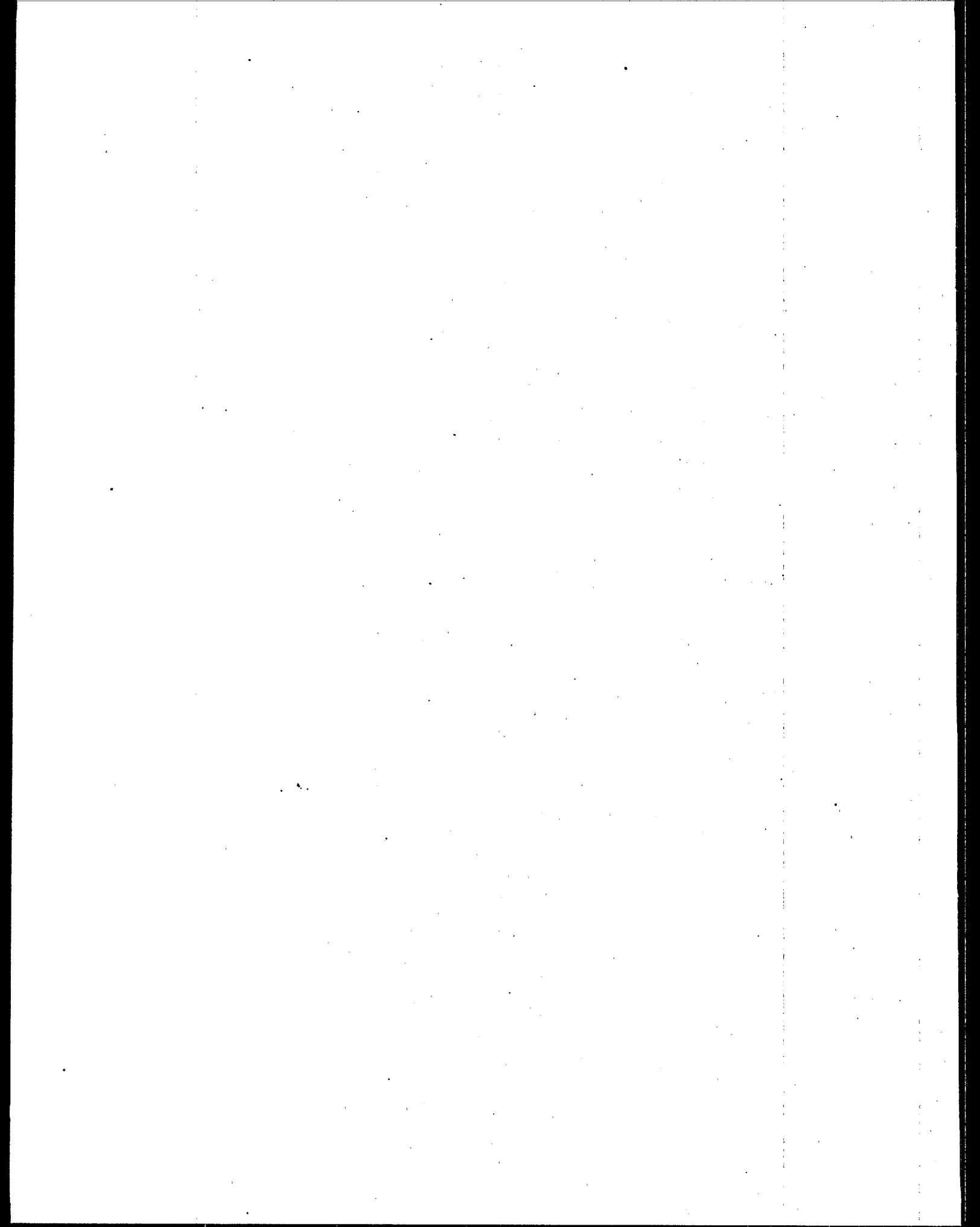
Chapter F6: Benefits Analysis for the Brayton Point Station

This chapter presents the results of EPA's evaluation of the economic benefits associated with reductions in estimated current I&E at the Brayton Point Station. The economic benefits that are reported here are based on the values presented in Chapters F4 and F5, and EPA's estimates of current I&E at the facility (discussed in Chapter F3). Section F6-1 summarizes the estimates of economic loss developed using the benefits transfer (BT) approach, presented in Chapter F4, and the habitat replacement cost (HRC) approach, presented in Chapter

F5. Section F6-2 discusses the benefits of potential impingement and entrainment reductions using both the BT and the HRC approaches. Section F6-3 discusses the uncertainties in the analysis.

F6-1 SUMMARY OF CURRENT I&E AND ASSOCIATED ECONOMIC IMPACTS

The flowchart in Figure F6-1 summarizes how the economic estimates were derived from the I&E estimates presented in Chapter F3 and summarized in Tables F4-2, F4-3, F4-9 and F4-10. Figures F6-2 and F6-3 indicate the distribution of I&E losses by species category and associated economic values. These diagrams reflect losses with current technologies. All dollar values and loss percents reflect midpoints of the ranges for the categories of commercial, recreational, nonuse and forage species impacts.

The baseline economic loss due to I&E at Brayton Point Station was calculated in Chapters F4 and F5. In Chapter F4, total economic loss was estimated using a benefits transfer approach to estimate the commercial, recreational, forage, and nonuse values of fish lost to I&E. This is a demand driven approach, i.e., it focuses on the values that people place on fish. In Chapter F5, total economic loss was estimated by calculating the cost to increase fish populations using habitat restoration techniques. This is a supply driven approach, i.e., it focuses on the costs associated with increasing fish populations.

The total annual economic losses associated with each method are summarized in Table F6-1. These values range from $9,000 to $873,000 for impingement, and from $230,000 to $27.7 million for entrainment. The range of economic loss is developed by taking the midpoint of the benefits transfer results and the 90th percentile species results from the HRC approach.

Table F6-1: Total Baseline Economic Loss from I&E (2000$, annually)		
	Impingement	**Entrainment**
Benefits transfer approach (demand driven approach from Chapter F4)[a]	$9,077	$230,001
Habitat replacement cost approach (supply driven approach from Chapter F5)[b]	$873,400	$27,732,900
Range	$9,077 to $873,400	$230,001 to $27,732,900

NA = not yet available.
[a] Midpoint of Range from Chapter F4.
[b] Based on cost to restore 90th percentile species impacted. Note that the lower bound estimates from the HRC approach reflect restoration of only half the impacted fish species (i.e., the 50th percentile). As such, the low end values for HRC were not considered in establishing the range of losses.

F6-2 POTENTIAL ECONOMIC BENEFITS DUE TO REGULATION

Table F6-2 summarizes the total annual benefits from I&E reductions, as well as remaining economic losses, under scenarios ranging from 10 percent to 90 percent reductions in I&E. Table F6-3 considers the benefits of two options with varying percent reductions of I&E. Table F6-3 indicates that the benefits of one option are expected to range from $2,000 to $175,000 for a 20 percent reduction in impingement and from $92,000 to $11.1 million for a 40 percent reduction in entrainment. The benefits of another option range from $5,000 to $524,000 for a 60 percent reduction in impingement and from $138,000 to $16.6 million for a 60 percent reduction in entrainment.

Table F6-2: Summary of Current Economic Losses and Benefits of a Range of Potential I&E Reductions at Brayton Point Station ($2000)

		Impingement	Entrainment	Total
Baseline Losses	low	$9,000	$230,000	$239,000
	high	$873,000	$27,733,000	$28,606,000
Benefits of 10% reductions	low	$1,000	$23,000	$24,000
	high	$87,000	$2,773,000	$2,861,000
Benefits of 20% reductions	low	$2,000	$46,000	$48,000
	high	$175,000	$5,547,000	$5,721,000
Benefits of 30% reductions	low	$3,000	$69,000	$72,000
	high	$262,000	$8,320,000	$8,582,000
Benefits of 40% reductions	low	$4,000	$92,000	$96,000
	high	$349,000	$11,093,000	$11,443,000
Benefits of 50% reductions	low	$5,000	$115,000	$120,000
	high	$437,000	$13,866,000	$14,303,000
Benefits of 60% reductions	low	$5,000	$138,000	$143,000
	high	$524,000	$16,640,000	$17,164,000
Benefits of 70% reductions	low	$6,000	$161,000	$167,000
	high	$611,000	$19,413,000	$20,024,000
Benefits of 80% reductions	low	$7,000	$184,000	$191,000
	high	$699,000	$22,186,000	$22,885,000
Benefits of 90% reductions	low	$8,000	$207,000	$215,000
	high	$786,000	$24,960,000	$25,746,000

Table F6-3: Summary of Benefits of Potential I&E Reductions at Brayton Point Station ($2000)

		Impingement	Entrainment	Total
20% reduced impingement and 40% reduced entrainment	low	$2,000	$92,000	$94,000
	high	$175,000	$11,093,000	$11,268,000
50% reduced impingement and 60% reduced entrainment[1]	low	$5,000	$138,000	$143,000
	high	$524,000	$16,640,000	$17,164,000

Figure F6-1: Overview and Summary of Average Annual I&E at Brayton Point Station and Associated Economic Values (based on I&E averaged over the period 1974-83 and adjusted for current operations; all results are annualized)[a]

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┌──────────────────────────────────────────────────────┐
│ 1. Number of organisms lost (eggs, larvae, juveniles, etc.)[b]  │ Production
│    I: 44,800 organisms                               │ foregone
│    E: 16.7 billion organisms                         │
└──────────────────────────────────────────────────────┘
                        │
                        ▼
┌──────────────────────────────────────────────────────┐
│ 2. Age 1 equivalents lost (number of fish)[c]        │ Replace-
│    I: 69,300 fish (40,300 forage, 29,000 commercial and recreational)  │ ment
│    E: 3.8 million fish (3.2 million forage, 605,700 commercial and recreational)  │
└──────────────────────────────────────────────────────┘
                        │
                        ▼
┌──────────────────────────────────────────────────────┐
│ 3. Loss to fishery (recreational and commercial harvest)[c]  │
│    I: 3,500 fish (5,100 lb)                           │
│    E: 43,000 fish (70,400 lb)                         │
└──────────────────────────────────────────────────────┘
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4. Value of commercial losses
I: 3,200 fish (4,116 lb)
$6,800 (74.7% of $I loss)
E: 37,700 fish (54,500 lb)
$173,300 (75.4% of $E loss)

5. Value of recreational losses
I: 308 fish (975 lb)
$1,400 (15.4% of $I loss)
E: 5,300 fish (15,900 lb)
$30,700 (13.4% of $E loss)

6. Value of forage losses (valued using either replacement cost method or as production foregone to fishery yield)
I: 40,300 fish
$200 (2.2% of $I loss)
E: 3.2 million fish
$10,600 (4.6% of $E loss)

7. Value of nonuse losses
I: $700 (7.7% of $I loss)
E: $15,400 (6.7% of $E loss)

8. Habitat replacement cost[d]
I: $873,000 per year
E: $27,733,000 per year

[a] All dollar values are the midpoint of the range of estimates.
[b] From Table F3-10 of Chapter F3.
[c] From Tables F4-2, F4-3, F4-9, and F4-10 of Chapter F4.
[d] Excluding estimated HRC costs for artificial reef emplacement, as discussed in Chapter F5.
Note: Species with I&E <1 percent of the total I&E were not valued.

Figure B6-2: Brayton Point: Distribution of Impingement Losses by Species Category and Associated Economic Values
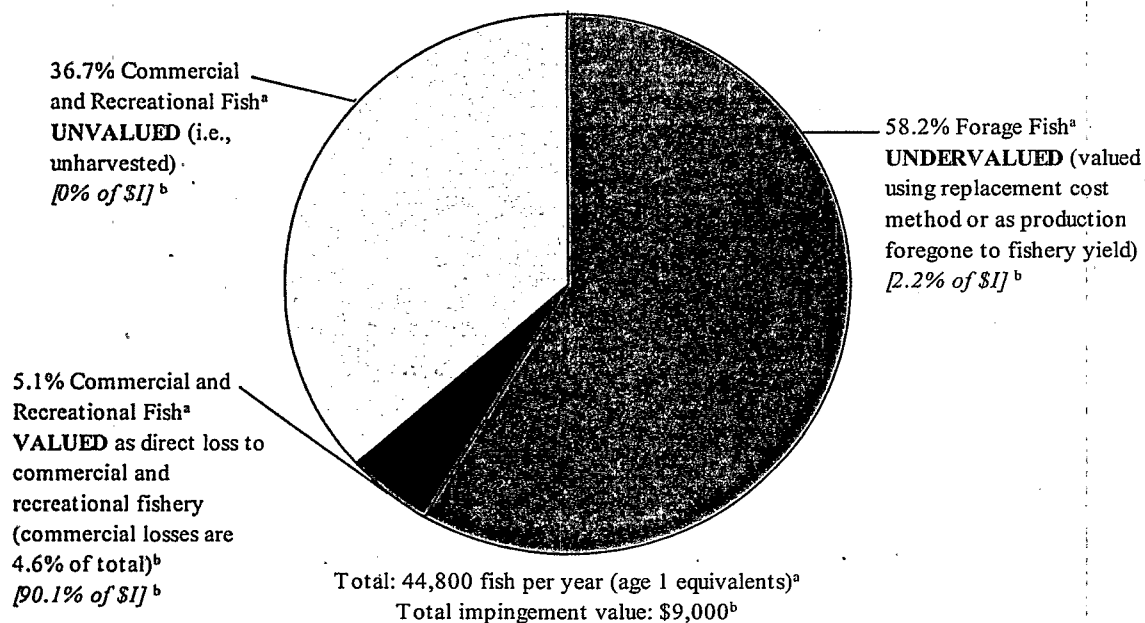
36.7% Commercial and Recreational Fish[a] **UNVALUED** (i.e., unharvested) *[0% of $I]* [b]

58.2% Forage Fish[a] **UNDERVALUED** (valued using replacement cost method or as production foregone to fishery yield) *[2.2% of $I]* [b]

5.1% Commercial and Recreational Fish[a] **VALUED** as direct loss to commercial and recreational fishery (commercial losses are 4.6% of total)[b] *[90.1% of $I]* [b]

Total: 44,800 fish per year (age 1 equivalents)[a]
Total impingement value: $9,000[b]

[a] Impacts shown are to age 1 equivalent fish, except impacts to the commercially and recreationally harvested fish include impacts for all ages vulnerable to the fishery.
[b] Midpoint of estimated range. Nonuse values are 7.7 percent of total estimated $I loss.

Figure F6-3: Brayton: Distribution of Entrainment Losses by Species Category and Associated Economic Values
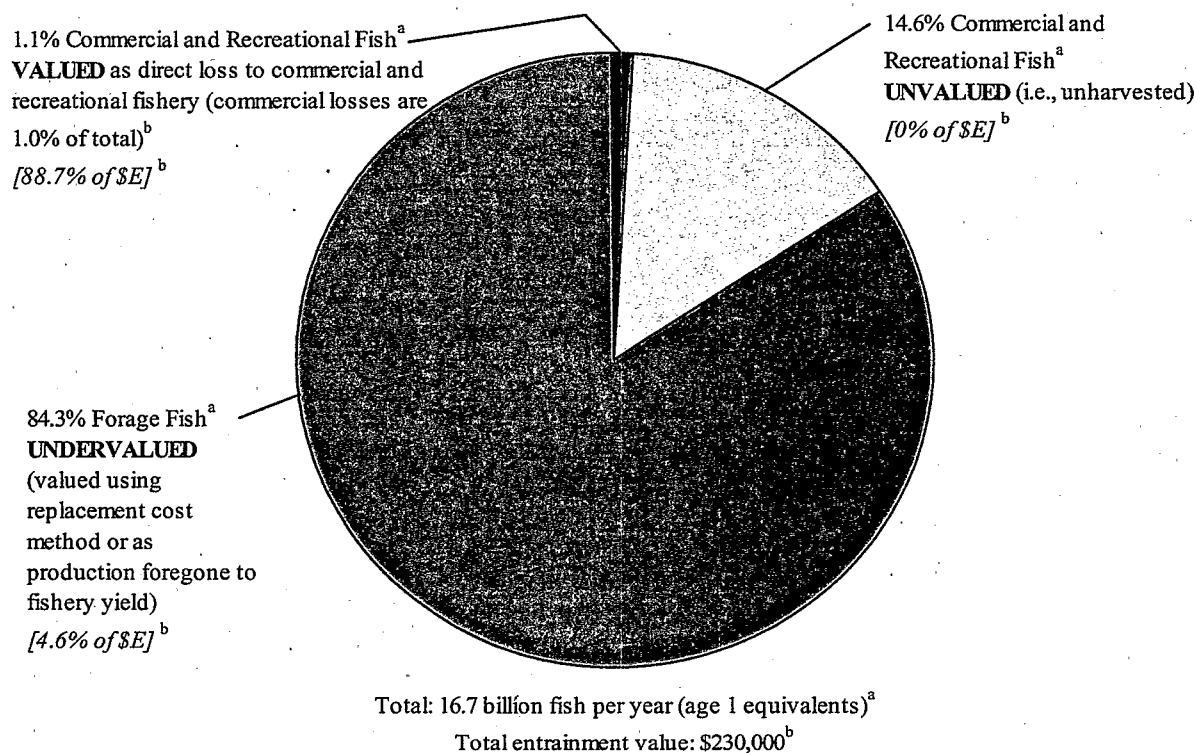
1.1% Commercial and Recreational Fish[a]
VALUED as direct loss to commercial and
recreational fishery (commercial losses are
1.0% of total)[b]
[88.7% of $E] [b]

14.6% Commercial and
Recreational Fish[a]
UNVALUED (i.e., unharvested)
[0% of $E] [b]

84.3% Forage Fish[a]
UNDERVALUED
(valued using
replacement cost
method or as
production foregone to
fishery yield)
[4.6% of $E] [b]

Total: 16.7 billion fish per year (age 1 equivalents)[a]
Total entrainment value: $230,000[b]

[a] Impacts shown are to age 1 equivalent fish, except impacts to the commercially and recreationally harvested fish include impacts for all ages
vulnerable to the fishery.
[b] Midpoint of estimated range. Nonuse values are 6.7 percent of total estimated $E loss.

F6-3 SUMMARY OF OMISSIONS, BIASES, AND UNCERTAINTIES IN THE BENEFITS ANALYSIS

Table F6-4 presents an overview of omissions, biases, and uncertainties in the benefits estimates. Factors with a negative impact on the benefits estimate bias the analysis downward, and therefore would raise the final estimate if they were properly accounted.

Table F6-4: Omissions, Biases, and Uncertainties in the Benefits and HRC Estimates		
Issue	**Impact on Benefits Estimate**	**Comments**
Used data from 1974-1983 as baseline for calculating I&E figures	Understates benefits[a]	There is data suggesting a plant-impacted declining fishery before 1985. Therefore numbers based on 1974-1983 may underestimate the full impact that Brayton I&E would have on a healthy fishery.
Long-term fish stock effects not considered	Understates benefits[a]	EPA assumed that the effects on stocks are the same each year, and that the higher fish kills would not have cumulatively greater impact.
Effect of interaction with other environmental stressors	Understates benefits[a]	EPA did not analyze how the yearly reductions in fish may make the stock more vulnerable to other environmental stressors. In addition, as water quality improves over time due to other watershed activities, the number of fish impacted by I&E may increase.
Recreation participation is held constant[a]	Understates benefits[a]	Recreational benefits only reflect anticipated increase in value per activity outing; increased levels of participation are omitted.
Boating, bird-watching, and other in-stream or near-water activities are omitted[a]	Understates benefits[a]	The only impact to recreation considered is fishing.
Did not count benefits for artificial reef installation for the tautog	Uncertain	As explained above in Section F5-6.3, the available information suggests very high restoration costs to offset I&E losses for just the tautog, which makes up only 0.8 percent of the I&E losses at Brayton Point. This result may be correct, but further investigation of potential tautog productivity at reefs is warranted. Therefore, EPA did not include these values in the HRC total benefits estimate.
HRC based on capture data assumed to represent age 1 fish	Understates benefits[a]	High percent of less than age 1 fish observed in capture data, thereby leading to potential underestimate of scale of restoration required.
Effect of change in stocks on number of landings	Uncertain	EPA assumed a linear stock to harvest relationship (e.g., that a 13 percent change in stock would have a 13 percent change in landings); this may be low or high, depending on the condition of the stocks.
Nonuse benefits	Uncertain	EPA assumed that nonuse benefits are 50 percent of recreational angling benefits.
Recreation values for various geographic areas	Uncertain	Some recreational values used are from various regions beyond the Brayton Point region.

[a] Benefits would be greater than estimated if this factor were considered.

Chapter F7:
Conclusions

As discussed in Chapter F3, EPA estimates that the cumulative impingement impact of the Brayton Point Station is 69,300 age 1 equivalents or 5,100 pounds of lost fishery yield per year. The cumulative entrainment impact amounts to 3.8 million age 1 equivalents or 70,400 pounds of lost fishery yield each year.

The results of EPA's evaluation of the dollar value of I&E losses at Brayton Point (as calculated using benefits transfer, in Chapter F4) indicate that baseline economic losses range from $6,500 to $11,600 per year for impingement and from $163,400 to $296,600 per year for entrainment (all in $2000).

EPA also developed an HRC analysis to examine the costs of restoring lost impinged and entrained organisms (Chapter F5). Using the HRC approach, the value of I&E losses at Brayton Point are approximately $873,000 per year for impingement, and over $27.7 million per year for entrainment (HRC annualized at 7 percent over 20 years, in keeping with estimates for compliance costs). These HRC estimates were merged with the benefits transfer results (from Chapter F4) to develop a comprehensive estimate of the potential benefits of reducing I&E (summarized in Chapter F6). Benefits were estimated for different levels of I&E reduction, ranging from 10 percent to 90 percent reductions in I&E. The resulting estimates of the potential economic benefits of reduced I&E ranged from $5,000 to $524,000 per year for a 60% reduction in impingement and from $161,000 to $19.4 million per year for a 70% reduction in entrainment (all in $2000).

For a variety of reasons, EPA believes that the estimates developed here underestimate the total economic benefits of reducing I&E at Brayton Point. EPA assumed that the effects of I&E on fish populations are constant over time (i.e., that fish kills do not have cumulatively greater impacts on diminished fish populations). EPA also did not analyze whether the number of fish affected by annual I&E would increase as populations increase in response to improved water quality, fishing restrictions to rebuild depleted stocks, or other improvements in environmental conditions. In the economic analyses, EPA also assumed that fishing is the only recreational activity affected.
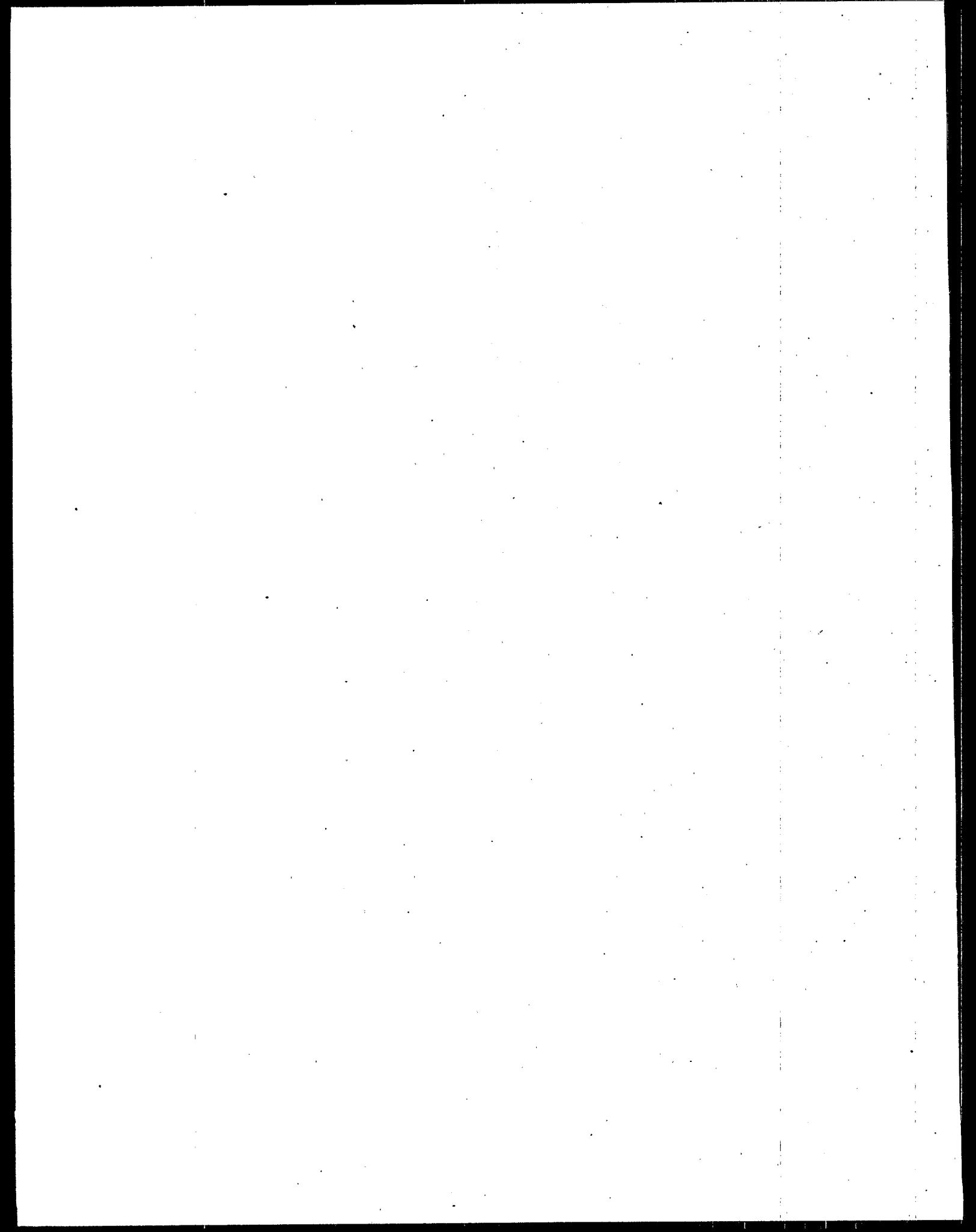
Appendix F1: Life History Parameter Values Used to Evaluate I&E

The tables in this appendix present the life history parameter values used by EPA to calculate age 1 equivalents, fishery yields, and production foregone from I&E data for the Brayton Point facility. Life history data were primarily obtained from the Brayton Point Permit Renewal Application reviewed by the Brayton Point Technical Advisory Committee (PG&E National Energy Group, Appendix F, 1999c). If not available in the Permit Renewal Application, the data were compiled from a variety of other sources, with a focus on obtaining data on local stocks whenever possible. The fishing mortality rates recommended for stock rebuilding were used, when available. These rates were obtained from the Northeast Fishery Science Center (NOAA, 2001c).

Table F1–1: Alewife Species Parameters				
Stage Name	Natural Mortality[a] (per stage)	Fishing Mortality[a] (per stage)	Fraction Vulnerable to Fishery[b]	Weight (lb)
Eggs	0.544	0	0	0.000022[c]
Larvae	5.5	0	0	0.00022[c]
Juvenile 1	2.57	0	0	0.00478[a]
Age 1+	1.04	0	0	0.0443[a]
Age 2+	1.04	0	0	0.139[a]
Age 3+	1.04	0	0	0.264[a]
Age 4+	1.04	0	0	0.386[a]
Age 5+	1.04	0	0	0.489[a]
Age 6+	1.04	0	0	0.568[a]
Age 7+	1.04	0	0	0.626[a]
Age 8+	1.04	0	0	0.667[a]
Age 9+	1.04	0	0	0.696[a]

[a] PG&E National Energy Group, 2001.
[b] Not a commercial or recreational species, thus no fishing mortality.
[c] Assumed based on data in PG&E National Energy Group (2001).

Table F1-2: Atlantic Menhaden Species Parameters

Stage Name	Natural Mortality[a] (per stage)	Fishing Mortality[a] (per stage)	Fraction Vulnerable to Fishery[b]	Weight (lb)
Eggs	1.2	0	0	0.000022[c]
Larvae	4.47	0	0	0.00022[c]
Juvenile 1	6.19	0	0	0.000684[a]
Age 1+	0.54	0	0	0.0251[a]
Age 2+	0.45	1.12	0.5	0.235[a]
Age 3+	0.45	1.12	1	0.402[a]
Age 4+	0.45	1.12	1	0.586[a]
Age 5+	0.45	1.12	1	0.863[a]
Age 6+	0.45	1.12	1	1.08[a]
Age 7+	0.45	1.12	1	1.27[a]
Age 8+	0.45	1.12	1	1.43[a]

[a] PG&E National Energy Group, 2001.
[b] Commercial species. Fraction vulnerable assumed.
[c] Assumed based on data in PG&E National Energy Group (2001).

Table F1-3: American Sand Lance Species Parameters

Stage Name	Natural Mortality[a] (per stage)	Fishing Mortality[b] (per stage)	Fraction Vulnerable to Fishery[b]	Weight (lb)
Eggs	1.41	0	0	0.000022[c]
Larvae	2.97	0	0	0.00022[c]
Juvenile 1	2.9	0	0	0.00119[a]
Age 1+	1.89	0	0	0.00384[a]
Age 2+	0.364	0	0	0.0073[a]
Age 3+	0.364	0	0	0.0113[a]
Age 4+	0.364	0	0	0.0153[a]
Age 5+	0.364	0	0	0.0191[a]
Age 6+	0.364	0	0	0.0225[a]
Age 7+	0.72	0	0	0.0255[a]
Age 8+	0.72	0	0	0.028[a]
Age 9+	0.72	0	0	0.0301[a]
Age 10+	0.72	0	0	0.0319[a]
Age 11+	0.72	0	0	0.0333[a]

[a] PG&E National Energy Group, 2001.
[b] Not a commercial or recreational species, thus no fishing mortality.
[c] Assumed based on data in PG&E National Energy Group (2001).

Table F1-4: Atlantic Silverside Species Parameters

Stage Name	Natural Mortality[a] (per stage)	Fishing Mortality[a] (per stage)	Fraction Vulnerable to Fishery[b]	Weight (lb)
Eggs	1.41	0	0	0.000022[c]
Larvae	5.81	0	0	0.00022[c]
Juvenile 1	2.63	0	0	0.0049[a]
Age 1+	3	0	0	0.0205[a]
Age 2+	6.91	0	0	0.0349[a]

[a] PG&E National Energy Group, 2001.
[b] Not a commercial or recreational species, thus no fishing mortality.
[c] Assumed based on data in PG&E National Energy Group (2001).

Table F1-5: Bay Anchovy Species Parameters

Stage Name	Natural Mortality[a] (per stage)	Fishing Mortality[a] (per stage)	Fraction Vulnerable to Fishery[b]	Weight (lb)
Eggs	1.1	0	0	0.000022[c]
Larvae	7.19	0	0	0.00022[c]
Juvenile 1	2.09	0	0	0.00104[a]
Age 1+	2.3	0	0	0.0037[a]
Age 2+	2.3	0	0	0.00765[a]
Age 3+	2.3	0	0	0.0126[a]

[a] PG&E National Energy Group, 2001.
[b] Not a commercial or recreational species, thus no fishing mortality.
[c] Assumed based on data in PG&E National Energy Group (2001).

Table F1-6: Butterfish Species Parameters

Stage Name	Natural Mortality (per stage)	Fishing Mortality[d] (per stage)	Fraction Vulnerable to Fishery[e]	Weight (lb)[f]
Eggs	2.3[a]	0	0	0.000000002[g]
Larvae	7.56[b]	0	0	0.000002[g]
Age 1+	0.8[c]	1.6	0.5	0.0272[h]
Age 2+	0.8[c]	1.6	1	0.0986[h]
Age 3+	0.8[c]	1.6	1	0.944[h]

[a] Calculated from survival for Atlantic silverside (Stone & Webster Engineering Corporation, 1977) using the using the equation: (natural mortality) = -LN(survival) - (fishing mortality).
[b] Calculated from extrapolated survival using the using the equation: (natural mortality) = -LN(survival) - (fishing mortality).
[c] NOAA, 2001b.
[d] NOAA, 2001b. $F_{0.1}$ for Gulf of Maine - Middle Atlantic.
[e] Commercial species. Fraction vulnerable assumed.
[f] Weight calculated from length using the formula: $(4.0 \times 10^{-6}) \ast \text{Length(mm)}^{3.26}$ = weight(g) (Froese and Pauly, 2001).
[g] Length from Able and Fahay (1998).
[h] Length from Scott and Scott (1988). Eastern United States.

Table F1-7: Hogchoker Species Parameters

Stage Name	Natural Mortality[a] (per stage)	Fishing Mortality[b] (per stage)	Fraction Vulnerable to Fishery[b]	Weight (lb)
Eggs	1.04	0	0	0.00022[c]
Larvae	5.2	0	0	0.0011[c]
Juvenile 1	2.31	0	0	0.00207[a]
Age 1+	2.56	0	0	0.0113[a]
Age 2+	0.705	0	0	0.0313[a]
Age 3+	0.705	0	0	0.061[a]
Age 4+	0.705	0	0	0.0976[a]
Age 5+	0.705	0	0	0.138[a]
Age 6+	0.705	0	0	0.178[a]

[a] PG&E National Energy Group, 2001.
[b] Not a commercial or recreational species, thus no fishing mortality.
[c] Assumed based on data in PG&E National Energy Group (2001).

Table F1-8: Rainbow Smelt Species Parameters

Stage Name	Natural Mortality[a] (per stage)	Fishing Mortality[b] (per stage)	Fraction Vulnerable to Fishery[c]	Weight (lb)
Eggs	4.44	0	0	0.00022[d]
Larvae	3.12	0	0	0.0011[d]
Juvenile 1	1.39	0	0	0.00395[a]
Age 1+	1	0.04	0.5	0.0182[a]
Age 2+	1	0.04	1	0.046[a]
Age 3+	1	0.04	1	0.085[a]
Age 4+	1	0.04	1	0.131[a]
Age 5+	1	0.04	1	0.18[a]
Age 6+	1	0.04	1	0.228[a]

[a] PG&E National Energy Group, 2001.
[b] Stone & Webster Engineering Corporation, 1977.
[c] Commercial species. Fraction vulnerable assumed.
[d] Assumed based on data in PG&E National Energy Group (2001).

Table F1-9: Scup Species Parameters

Stage Name	Natural Mortality[a] (per stage)	Fishing Mortality[b] (per stage)	Fraction Vulnerable to Fishery[a]	Weight (lb)
Eggs	1.43	0	0	0.00022[c]
Larvae	4.55	0	0	0.0011[c]
Juvenile 1	3.36	0	0	0.028[a]
Age 1+	0.383	0	0	0.132[a]
Age 2+	0.383	0	0	0.322[a]
Age 3+	0.383	0.14	0.5	0.572[a]
Age 4+	0.383	0.14	1	0.845[a]
Age 5+	0.383	0.14	1	1.12[a]
Age 6+	0.383	0.14	1	1.37[a]
Age 7+	0.383	0.14	1	1.59[a]
Age 8+	0.383	0.14	1	1.78[a]
Age 9+	0.383	0.14	1	1.94[a]
Age 10+	0.383	0.14	1	2.07[a]
Age 11+	0.383	0.14	1	2.23[a]

[a] PG&E National Energy Group, 2001.
[b] NOAA, 2001c. $F_{0.1}$ for Southern New England - Middle Atlantic.
[c] Assumed based on data in PG&E National Energy Group (2001).

Table F1-10: Seaboard Goby Species Parameters

Stage Name	Natural Mortality[a] (per stage)	Fishing Mortality[a] (per stage)	Fraction Vulnerable to Fishery[a]	Weight (lb)
Eggs	0.288	0	0	0.000022[b]
Larvae	4.09	0	0	0.00022[b]
Juvenile 1	2.3	0	0	0.000485[a]
Age 1+	2.55	0	1	0.00205[a]

[a] PG&E National Energy Group, 2001.
[b] Assumed based on data in PG&E National Energy Group (2001).

Table F1-11: Silver Hake Species Parameters

Stage Name	Natural Mortality (per stage)	Fishing Mortality[d] (per stage)	Fraction Vulnerable to Fishery[e]	Weight (lb)[f]
Eggs	1.22[a]	0	0	0.000000006[g]
Larvae	10.5[b]	0	0	0.00203[h]
Age 1+	0.36[c]	0	0	0.164[g]
Age 2+	0.36[c]	0	0	0.478[g]
Age 3+	0.36[c]	0.39	0.5	0.804[g]
Age 4+	0.36[c]	0.39	1	1.48[h]
Age 5+	0.36[c]	0.39	1	2.15[h]
Age 6+	0.36[c]	0.39	1	3[h]
Age 7+	0.36[c]	0.39	1	4.06[h]
Age 8+	0.36[c]	0.39	1	5.35[h]
Age 9+	0.36[c]	0.39	1	6.89[h]
Age 10+	0.36[c]	0.39	1	8.72[h]
Age 11+	0.36[c]	0.39	1	10.4[h]
Age 12+	0.36[c]	0.39	1	11.3[g]

[a] Saila et al., 1997. Red hake.
[b] Calculated from extrapolated survival using the using the equation: (natural mortality) = -LN(survival) - (fishing mortality).
[c] Froese and Pauly, 2001.
[d] NOAA, 2001c. $F_{0.1}$ for southern stock.
[e] Commercial species. Fraction vulnerable assumed.
[f] Weight calculated from length using the formula: $(3.79 \times 10^{-6}) \ast \text{Length(mm)}^{3.17} = \text{weight(g)}$ (Froese and Pauly, 2001).
[g] Length from Scott and Scott (1988).
[h] Length assumed based on Scott and Scott (1988).

Table F1-12: Striped Killifish Species Parameters

Stage Name	Natural Mortality (per stage)	Fishing Mortality[c] (per stage)	Fraction Vulnerable to Fishery[c]	Weight (lb)[d]
Eggs	2.3[a]	0	0	0.0000009[e]
Larvae	2.14[b]	0	0	0.00002[e]
Age 1+	0.777[b]	0	0	0.0121[f]
Age 2+	0.777[b]	0	0	0.0327[f]
Age 3+	0.777[b]	0	0	0.0551[f]
Age 4+	0.777[b]	0	0	0.0778[f]
Age 5+	0.777[b]	0	0	0.0967[f]
Age 6+	0.777[b]	0	0	0.113[f]
Age 7+	0.777[b]	0	0	0.158[f]

[a] Calculated from survival for Atlantic silverside (Stone & Webster Engineering Corporation, 1977) using the using the equation: (natural mortality) = -LN(survival) - (fishing mortality).
[b] Calculated from survival for mummichog (Meredith and Lotrich, 1979) using the using the equation: (natural mortality) = -LN(survival) - (fishing mortality).
[c] Not a commercial or recreational species, thus no fishing mortality.
[d] Weight calculated from length using the formula: $(2.6 \times 10^{-5}) \ast \text{Length(mm)}^{2.96} = \text{weight(g)}$ (Carlander, 1969).
[e] Length from Able and Fahay (1998).
[f] Length from Carlander (1969).

Table F1-13: Tautog Species Parameters				
Stage Name	Natural Mortality[a] (per stage)	Fishing Mortality[b] (per stage)	Fraction Vulnerable to Fishery[c]	Weight (lb)
Eggs	1.4	0	0	0.0022[d]
Larvae	5.86	0	0	0.022[d]
Juvenile 1	5.02	0	0	0.0637[a]
Age 1+	0.175	0	0	0.217[a]
Age 2+	0.175	0	0	0.44[a]
Age 3+	0.175	0	0	0.734[a]
Age 4+	0.175	0	0	1.08[a]
Age 5+	0.175	0	0	1.48[a]
Age 6+	0.175	0	0	1.89[a]
Age 7+	0.175	0	0	2.32[a]
Age 8+	0.175	0	0	2.76[a]
Age 9+	0.175	0.15	0.5	3.18[a]
Age 10+	0.175	0.15	1	3.6[a]
Age 11+	0.175	0.15	1	4[a]
Age 12+	0.175	0.15	1	4.38[a]
Age 13+	0.175	0.15	1	4.73[a]
Age 14+	0.175	0.15	1	5.07[a]
Age 15+	0.175	0.15	1	5.38[a]
Age 16+	0.175	0.15	1	5.67[a]
Age 17+	0.175	0.15	1	5.94[a]
Age 18+	0.175	0.15	1	6.19[a]
Age 19+	0.175	0.15	1	6.42[a]
Age 20+	0.175	0.15	1	6.63[a]
Age 21+	0.175	0.15	1	6.82[a]
Age 22+	0.175	0.15	1	6.99[a]
Age 23+	0.175	0.15	1	7.15[a]
Age 24+	0.175	0.15	1	10[a]

[a] PG&E National Energy Group, 2001.
[b] Atlantic States Marine Fisheries Commission, 2000h. F_{target}.
[c] Commercial and recreational species. Fraction vulnerable assumed.
[d] Assumed based on data in PG&E National Energy Group (2001).

Table F1-14: Threespine Stickleback Species Parameters

Stage Name	Natural Mortality[a] (per stage)	Fishing Mortality[a] (per stage)	Fraction Vulnerable to Fishery[b]	Weight (lb)
Eggs	0.288	0	0	0.00022[c]
Larvae	2.12	0	0	0.0011[c]
Juvenile 1	1.7	0	0	0.00377[a]
Age 1+	1.42	0	0	0.00917[a]
Age 2+	1.42	0	0	0.0112[a]
Age 3+	1.42	0	0	0.0116[a]

[a] PG&E National Energy Group, 2001.
[b] Not a commercial or recreational species, thus no fishing mortality.
[c] Assumed based on data in PG&E National Energy Group (2001).

Table F1-15: Weakfish Species Parameters

Stage Name	Natural Mortality[a] (per stage)	Fishing Mortality[b] (per stage)	Fraction Vulnerable to Fishery[a]	Weight (lb)
Eggs	1.04	0	0	0.000022[c]
Larvae	7.67	0	0	0.065[c]
Juvenile 1	2.44	0	0	0.13[c]
Juvenile 2	1.48	0	0	0.195[a]
Age 1+	0.349	0.5	0.1	0.26[a]
Age 2+	0.25	0.5	0.5	0.68[a]
Age 3+	0.25	0.5	1	1.12[a]
Age 4+	0.25	0.5	1	1.79[a]
Age 5+	0.25	0.5	1	2.91[a]
Age 6+	0.25	0.5	1	6.21[a]
Age 7+	0.25	0.5	1	7.14[a]
Age 8+	0.25	0.5	1	9.16[a]
Age 9+	0.25	0.5	1	10.8[a]
Age 10+	0.25	0.5	1	12.5[a]
Age 11+	0.25	0.5	1	12.5[a]
Age 12+	0.25	0.5	1	12.5[a]
Age 13+	0.25	0.5	1	12.5[a]
Age 14+	0.25	0.5	1	12.5[a]
Age 15+	0.25	0.5	1	12.5[a]

[a] PSEG, 1999c.
[b] Atlantic States Marine Fisheries Commission, 2000d. Management goal.
[c] Assumed based on data in PSEG (1999c).

Table F1-16: White Perch Species Parameters

Stage Name	Natural Mortality[a] (per stage)	Fishing Mortality[a] (per stage)	Fraction Vulnerable to Fishery[b]	Weight (lb)
Eggs	1.42	0	0	0.00022[c]
Larvae	4.59	0	0	0.0011[c]
Age 1+	0.693	0	0	0.0516[a]
Age 2+	0.693	0	0	0.156[a]
Age 3+	0.543	0.15	0.5	0.248[a]
Age 4+	0.543	0.15	1	0.331[a]
Age 5+	1.46	0.15	1	0.423[a]
Age 6+	1.46	0.15	1	0.523[a]
Age 7+	1.46	0.15	1	0.613[a]
Age 8+	1.46	0.15	1	0.658[a]
Age 9+	1.46	0.15	1	0.794[a]

[a] PG&E National Energy Group, 2001.
[b] Commercial and recreational species. Fraction vulnerable assumed.
[c] Assumed based on data in PG&E National Energy Group (2001).

Table F1-17: Windowpane Species Parameters

Stage Name	Natural Mortality[a] (per stage)	Fishing Mortality[b] (per stage)	Fraction Vulnerable to Fishery[c]	Weight (lb)
Eggs	1.41	0	0	0.0011[d]
Larvae	6.99	0	0	0.00165[d]
Juvenile 1	2.98	0	0	0.00223[a]
Age 1+	0.42	0	0	0.0325[a]
Age 2+	0.42	1.6	0.25	0.122[a]
Age 3+	0.42	1.6	0.61	0.265[a]
Age 4+	0.42	1.6	1	0.433[a]
Age 5+	0.42	1.6	1	0.603[a]
Age 6+	0.42	1.6	1	0.761[a]
Age 7+	0.42	1.6	1	0.899[a]
Age 8+	0.42	1.6	1	1.01[a]
Age 9+	0.42	1.6	1	1.11[a]
Age 10+	0.42	1.6	1	1.19[a]

[a] PG&E National Energy Group, 2001.
[b] NOAA, 2001c. F_{target} for Southern New England - Middle Atlantic.
[c] USGen New England, 2001.
[d] Assumed based on data in PG&E National Energy Group (2001).

Table F1-18: Winter Flounder Species Parameters

Stage Name	Natural Mortality[a] (per stage)	Fishing Mortality[b] (per stage)	Fraction Vulnerable to Fishery[c]	Weight (lb)
Eggs	0.288	0	0	0.0022[d]
Larvae 1	2.05	0	0	0.00441[d]
Larvae 2	3.42	0	0	0.011[d]
Larvae 3	3.52	0	0	0.0176[d]
Larvae 4	0.177	0	0	0.022[d]
Juvenile 1	2.38	0	0	0.033[a]
Age 1+	1.1	0.24	0.01	0.208[a]
Age 2+	0.924	0.24	0.29	0.562[a]
Age 3+	0.2	0.24	0.8	0.997[a]
Age 4+	0.2	0.24	0.92	1.42[a]
Age 5+	0.2	0.24	0.83	1.78[a]
Age 6+	0.2	0.24	0.89	2.07[a]
Age 7+	0.2	0.24	0.89	2.29[a]
Age 8+	0.2	0.24	0.89	2.45[a]
Age 9+	0.2	0.24	0.89	2.57[a]
Age 10+	0.2	0.24	0.89	2.65[a]
Age 11+	0.2	0.24	0.89	2.71[a]
Age 12+	0.2	0.24	0.89	2.75[a]
Age 13+	0.2	0.24	0.89	2.78[a]
Age 14+	0.2	0.24	0.89	2.8[a]
Age 15+	0.2	0.24	0.89	2.82[a]
Age 16+	0.2	0.24	0.89	2.83[a]

[a] PG&E National Energy Group, 2001.
[b] NOAA, 2001c. F_{target} for Southern New England - Middle Atlantic.
[c] Colarusso, 2000.
[d] Assumed based on data in PG&E National Energy Group (2001).

Part G: Seabrook and Pilgrim Facilities Case Study
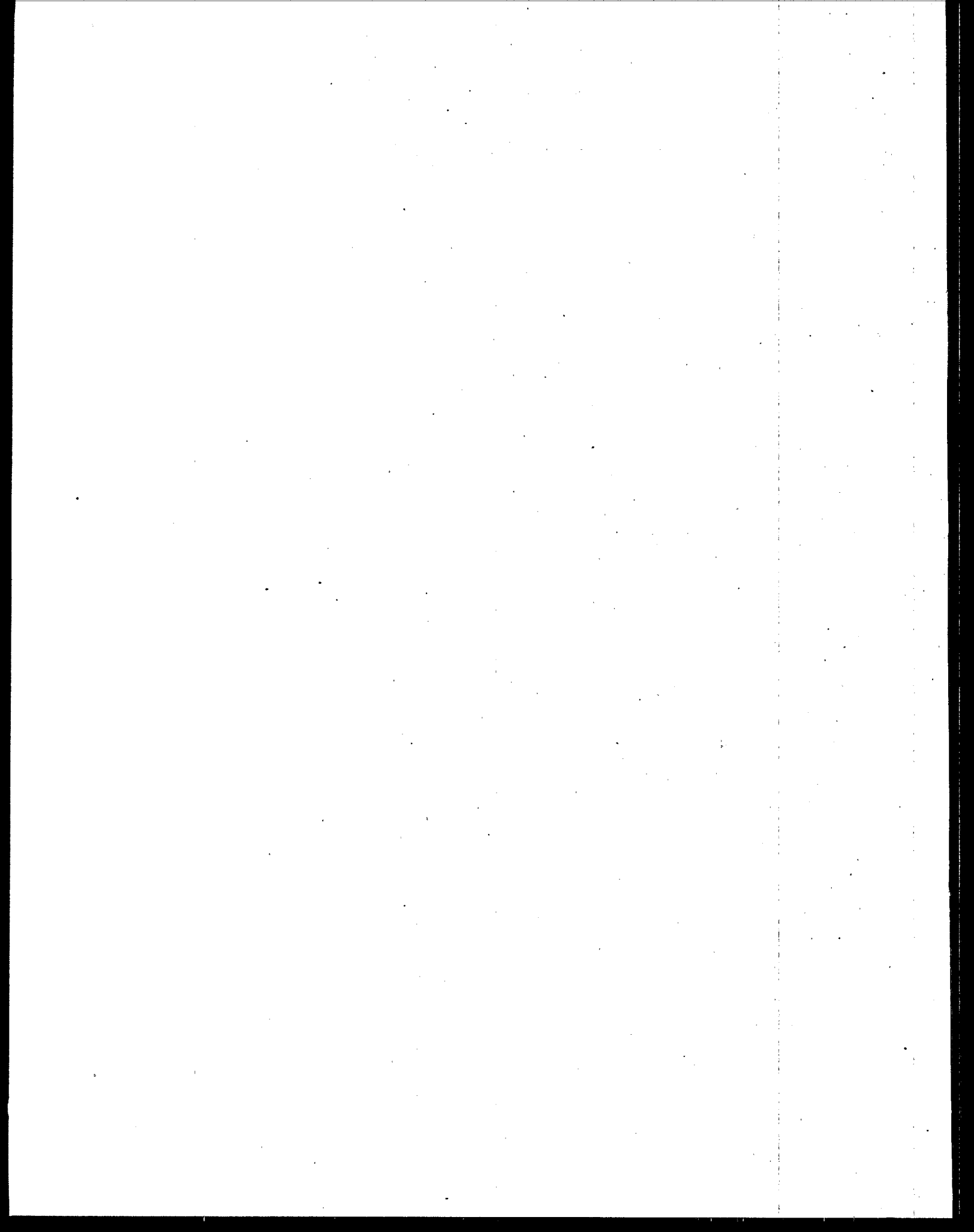
Chapter G1: Background

This report presents the results of an evaluation of two New England coastal facilities, the Seabrook Nuclear Power Station in Seabrook, New Hampshire, and the Pilgrim Nuclear Power Station in Plymouth, Massachusetts. The facilities are located in the same ecological region, but differ in the locations of their CWIS: Seabrook's intakes are located over 1 mile offshore, in relatively deep waters, whereas the Pilgrim intakes are located nearshore in an artificial embayment created by the construction of a series of breakwaters. Section G1-1 of this background chapter provides brief descriptions of the facilities, Section G1-2 describes the environmental setting, and Section G1-3 presents information on the socioeconomic characteristics of the areas near each facility.

G1-1 OVERVIEW OF CASE STUDY FACILITIES

Seabrook facility

The Seabrook facility is a two-unit 1240 MW nuclear power generating station (Normandeau Associates, 1999) located in southeastern New Hampshire just over the state line from Massachusetts and approximately 15 miles south of Portsmouth, New Hampshire (Figure G1-1). Seabrook is situated 3.2 km (2 mi) inland from the Atlantic coast on 364 hectares (889 acres) of land, 202 hectares (500 acres) of which are wetlands.

Commercial operation of the Seabrook station began in 1990. Seabrook had 840 employees in 1999 and generated 8.7 million MWh of electricity.[1] Estimated revenues in 1999 were $932 million, based on the plant's 1999 estimated electricity sales of 8.2 million MWh and the 1999 company-level electricity revenues of $113.42 per MWh. Seabrook's 1999 production expenses totaled almost $182 million, or 2.101 cents per kWh, for an operating income of $750 million.

Both Seabrook generating units use pressurized-water reactors and are equipped with a circulating water system for condensing steam back to feedwater (Normandeau Associates, 1999). The circulating water system uses 5,000 m (17,000 ft) long pipes to draw ocean water from Ipswich Bay via intakes 2,000 m (7,000 ft) offshore at a depth of 18 m (60 ft). Each intake is equipped with a 9 m (30 ft) diameter velocity cap to regulate the intake flow. The normal flow at the Seabrook facility is 811 MGD with a velocity of 0.5 fps. Once used, water in the cooling system is discharged through diffuser nozzles back into the Atlantic Ocean 1,700 m (5,500 ft) from the plant (New Hampshire Yankee Electric Company, 1986).

> ❖ *Ownership Information*
> **Seabrook** is a regulated utility plan operated by North Atlantic Energy Service Corporation, a subsidiary of Northeast Utilities (NU). Seabrook is jointly owned by several utility companies, with NU owning 40 percent, the largest share in the plant (Form EIA-860A, 2000). Through its subsidiaries, NU provides electric power to 1.7 million customers throughout New England. NU is a domestically focused company that had 9,260 employees in 2000 (Hoover's, 2001g). NU owns or controls more than 4,500 megawatts of capacity. During 2000, NU posted revenues of $5.9 billion and sold 75.6 million MWh of electricity (NU, 2001a,b).
>
> **Pilgrim** began operation as a regulated utility plant. In July 1999, Entergy Nuclear acquired the plant from Boston Edison. Entergy Nuclear is a division of Entergy Corporation. Entergy Corporation is a global, competitive energy company with 14,100 employees worldwide and a total generating capacity of more than 30,000 megawatts. In 2000, Entergy posted MWh sales of over 103 million and revenues of $10.0 billion (Hoover's, 2001e; Entergy Corporation, 2001).

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[1] One MWh equals 1,000 KWh.

Pilgrim facility

The Pilgrim facility is a 670 MW nuclear power plant on the northwest shore of Cape Cod Bay on Plymouth Bay (Entergy Nuclear General Company, 2000). The facility is about 61 km (38 mi) southeast of Boston and 71 km (44 mi) east of Providence, Rhode Island (Figure G1-1).

Figure G1-1: Locations of the New England Coastal Case Study Facilities
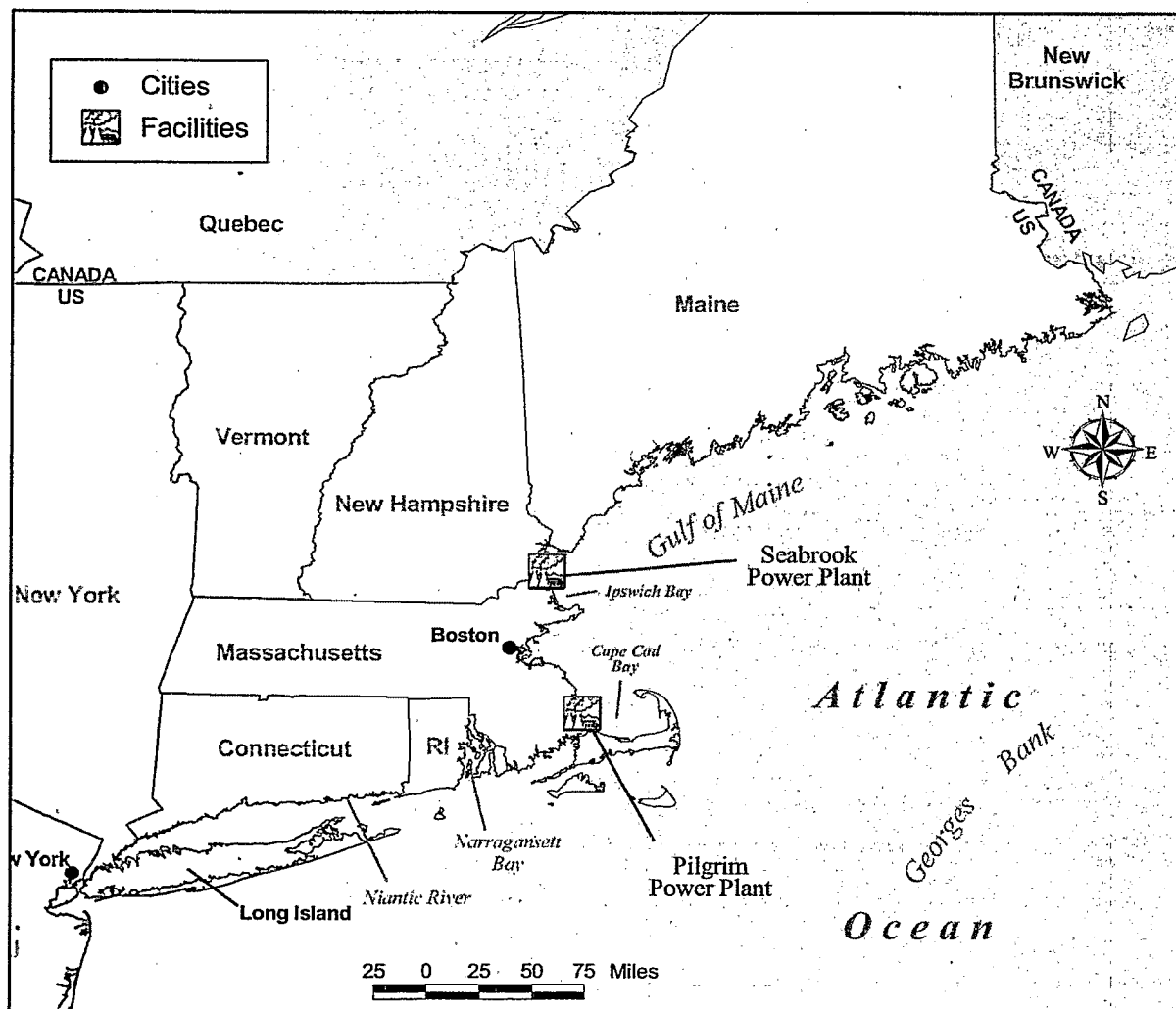
Commercial operation of the Pilgrim station began in 1972. In 1998, Pilgrim generated 5.7 million MWh of electricity. Estimated 1998 revenues for the Pilgrim plant were $597 million, based on the plant's 1998 estimated electricity sales of 5.3 million MWh and the 1998 company-level electricity revenues of $112.00 per MWh. Pilgrim's 1998 production expenses totaled $143 million, or 2.503 cents per kWh, for an operating income of $454 million.[2]

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[2] Pilgrim was sold to Entergy Nuclear, a nonutility, in July of 1999. Therefore, the FERC Form-1 data presented in this section are not available for 1999.

Pilgrim uses a boiling water reactor to produce steam and a once-through cooling system that draws its water from Plymouth Bay directly offshore from an embayment created when the facility constructed a series of breakwaters. The cooling system uses two pipes with an intake capacity of 224 MGD. The intake structure consists of wing walls, a skimmer wall, vertical bar racks, and vertical traveling screens to remove aquatic organisms and small debris. The intake approach velocity just before the screens is 1 fps (ENSR, 2000).

Table G1-1 summarizes the plant characteristics of the Seabrook and Pilgrim power plants.

Table G1-1: Summary of Seabrook and Pilgrim Plant Characteristics		
	Seabrook (1999)	**Pilgrim (1998)**
Plant EIA Code	6115	1590
NERC Region	NPCC	NPCC
Total Capacity (MW)	1,240	670
Primary Fuel	Uranium	Uranium
Number of Employees	840	670[a]
Net Generation (million MWh)	8.7	5.7
Estimated Revenues (million dollars)	932	597
Total Production Expense (million dollars)	182	143
Production Expense (¢/kWh)	2.101	2.503
Estimated Operating Income (million dollars)	750	454

Notes:　NERC　=　North American Electric Reliability Council
　　　　　NPCC　=　Northeast Power Coordinating Council
　　　　　Dollars are in $2001.
　　　　　[a] 1996 data.
Source: Form EIA-860A (NERC Region, Total Capacity, Primary Fuel); FERC Form-1 (Number of Employees, Total Production Expense); Form EIA-906 (Net Generation).

G1-2 ENVIRONMENTAL SETTING

G1-2.1 Gulf of Maine

The Seabrook and Pilgrim facilities are both on the Gulf of Maine, an area bounded to the south and east by tall underwater landforms called "banks" that form a barrier to the North Atlantic. The western and northern boundaries to the Gulf of Maine are defined by the coastlines of Massachusetts, New Hampshire, Maine, New Brunswick, and Nova Scotia.

The Seabrook facility is located on the Browns River near a salt marsh estuary, about 2 miles inland from the coast. The estuary is formed by the confluence of several waterways, including the Hampton, Browns, and Blackwater rivers and Mill Creek. Approximately 10% of the estuary is open water, and the remainder is salt marsh. Hampton Harbor, which is located at the mouth of the Browns River, is a shallow lagoon, roughly 1.9 km (1.2 mi) wide by 2.4 km (1.5 mi) long, behind the barrier beaches at Hampton and Seabrook (Normandeau Associates, 1994b).

The western shore of Plymouth Bay near the Pilgrim facility is a mix of sand beaches, bluffs, and boulder outcroppings (Kelly et al., 1992). The mouth of the Plymouth Bay estuary is approximately 6.4 km (4 mi) northwest of the Pilgrim facility.

G1-2.2 Aquatic Habitat and Biota

The aquatic community near the Seabrook facility is typical of that found in the northeastern United States waters (Normandeau Associates, 1999). The submerged rock surfaces near Seabrook support rich and diverse communities of attached algae and animals that are a rich food source for more than 30 fish species that use the area as a nursery as well as for rearing and forage. Several fish species found in the coastal waters near Seabrook support commercial and recreational fisheries, such as winter flounder (*Pleuronectes americanus*), yellowtail flounder (*Limanda ferruginea*), Atlantic cod (*Gadus morhua*), Atlantic mackerel (*Scomber scombrus*), and Atlantic herring (*Clupea harengus*). Forage fish such as Atlantic silverside (*Menidia menidia*) are also present in these waters.

The part of Cape Cod Bay where the Pilgrim facility is located is a zoogeographic boundary, marking the distributional limits for many marine organisms (Kelly et al., 1992). Many species typically associated with the seasonally warmer waters south of Cape Cod, e.g., spotted hake (*Urophycis regius*), oyster toadfish (*Opsanus tau*), and rainwater killifish (*Lucania parva*), occasionally move north into Cape Cod Bay in mid- to late summer. However, most northern species, e.g., rainbow smelt (*Osmerus mordax*), Atlantic tomcod (*Microgadus tomcod*), and rock gunnel (*Pholis gunnellus*), rarely extend into the waters south of Cape Cod Bay (Able and Fahay, 1998).

G1-2.3 Major Environmental Stressors

a. Habitat loss and alteration

The areas surrounding the Pilgrim and Seabrook facilities have long been inhabited, and support a wide range of human activities. As a result, there has been significant habitat alteration and loss because of wetlands draining/filling for construction of residential and commercial structures, as well as alterations to subaquatic habitats by fishing and onshore residential and industrial activities (e.g., laying of discharge pipes). One common alteration relates to the restriction of tidal flows to tidal wetlands through diking or the construction of roadways with improperly sized culverts among other causes. In these areas, as the tidal flows have been diminished or eliminated, the formerly salt-tolerant vegetation characteristic of a tidal wetland were colonized by less salt tolerant species, notably *Phragmites australis*, a tall reed grass that is native to New England. *Phragmites* grows in dense monoculture stands that reduce the ability of the habitat to support aquatic and terrestrial species.

b. Introduction of non-native species

There are concerns over the introduction of non-native species into the coastal habitats of Massachusetts through ship ballast water (MIT Sea Grant, 2001). One species that recently colonized southern Massachusetts waters is *Hemigrapsus sanguineus*, a crab native to the western North Pacific. *H. sanguineus* eats a variety of algae and animals, including juvenile clams, and affects the local ecology by competing for food and habitat space with native crab species, although it may also serve as a food source for larger animals (MIT Sea Grant, 2001).

Other invasive species include bittersweet (*Celastrus orbiculatus*) and saltspray rose (*Rosa rugosa*) (Manomet Center for Conservation Sciences, 2001).

c. Overfishing

Based on trends in catch and fishing effort, the National Marine Fisheries Service (NMFS) believes that the dominant factor affecting New England's commercial fish stocks is overfishing (NMFS, 1999b). NMFS statistics show that standardized trawl effort for groundfish in the Gulf of Maine approximately doubled from 1976 to 1988, yet fishermen saw a decline in landings and catch per unit effort during that period (Townsend and Larsen, 1992). The changes in commercial fish stocks brought about by overexploitation also have consequences for the noncommercial and recreational fish species.

d. Pollution

The large population and residential and industrial development near the Pilgrim and Seabrook facilities are a source of nonpoint source (NPS) pollution, which plays a major role in adversely affecting the quality and productivity of the nearby waters. When rainwater and snowmelt run over farm fields, city streets, timberland, and lawns, other pollutants such as soil sediments, fertilizers, sewage, and pesticides are picked up and deposited into surface water. Contaminated rainwater often runs directly into coastal waters such as salt marshes and estuaries, impairing water quality and reducing the productivity of coastal habitats. Because estuaries serve as the breeding grounds for fish and other wildlife, commercial fisheries are ultimately affected by NPS pollution (Massachusetts Office of Coastal Zone Management, 1994).

One of the most costly consequences of coastal NPS pollution is the closing of shellfish beds because of excessive fecal coliform counts. Between 1980 and 1994, shellfish bed closings increased dramatically, many the direct result of NPS pollution from septic systems and from domestic and farm animals (Massachusetts Office of Coastal Zone Management, 1994). Finally, the increase in nutrients entering shallow coastal ecosystems (NBEP, 1998) associated with NPS are seen as the most widespread factor altering the structure and function of aquatic systems by causing increased macroalgal biomass and growth. For example, the Waquoit Bay National Estuarine Research Reserve on Cape Cod has experienced a particular problem with increases in seaweeds, which have decreased the areas covered by eelgrass habitats. Eelgrass serves as a primary source of food, shelter, and spawning habitat for an abundance of marine life, including economically important finfish and shellfish species such as winter flounder, tautog (*Tautoga onitis*), bluefish (*Pomatomus saltator*), quahogs or hard clams (*Mercenaria mercenaria*), bay scallops (*Argopecten irradians*), soft-shelled clams (*Mya arenaria*), and blue crab (*Callinectes sapidus* Rathbun) (NBEP, 1998).

G1-3 SOCIOECONOMIC CHARACTERISTICS

In 2000, Rockingham County, where the Seabrook facility is located, had a population of 277,359, a home ownership rate of 75.6%, and a median household income of $54,161 (Table G1-2; U.S. Census Bureau, 2001). In 2000, Plymouth County, where the Pilgrim facility is located, had a population of 472,822, a home ownership rate of 75.6%, and a slightly lower median household income than Rockingham County (Table G1-2; U.S. Census Bureau, 2001).

Table G1-2: Socioeconomic Characteristics of Rockingham County, New Hampshire and Plymouth County, Massachusetts. Data from 2000 Except Where Shown.

	Rockingham County	Plymouth County
Population	277,359	472,822
Land area (square miles)	695	661
Persons per square mile	399.1	715.3
Median household money income (1997 model-based estimate)	$54,161	$49,165
Persons below poverty (%, 1997 model-based estimate)	5.1%	8.6%
Housing units	113,023	181,524
Home ownership rate	75.6%	75.6%
Households	104,529	168,361
Persons per household	2.63	2.74
Households with persons under 18 years (%)	38.1%	39.1%
High school graduates, persons 25 years and over (1990 data)	137,833	232,060
College graduates, persons 25 years and over (1990 data)	41,547	61,614

Source: U.S. Census Bureau, 2001.

G1-3.1 Major Industries

Tourism is a significant economic factor in the region near the Seabrook facility. The population around Seabrook typically doubles in the summer months (New Hampshire Estuaries Project, 2002). Other economic activities in the area include plastics, shoe, and furniture manufacturing, and metal fabrication. Most companies are small, with the largest employing 1,000 people. Total industrial employment is about 3,000 (New Hampshire Estuaries Project, 2002).

The town of Plymouth, near the Pilgrim facility, has relatively little industrial activity (State of Massachusetts, 2002); only approximately 1% of the land in the town is classified as commercial or industrial. Plymouth, however, is a major tourist destination, with beaches and the nearby attractions of Plymouth Rock and Plymouth Plantation, which mark where the Pilgrims landed in Massachusetts and portray life in their initial colony.

G1-3.2 Commercial Fisheries

Commercial fishing in New Hampshire has generated between $10.0 and $14.9 million of revenue per year for the past 10 years (personal communication, National Marine Fisheries Service, Fisheries Statistics and Economics Division, Silver Spring, MD, 2002). Tables G1-3 and G1-4 show the pounds harvested in New Hampshire and the revenue generated for commercial fisheries from 1990 to 2000. Atlantic cod was the most important commercial fish species, constituting 33% of the catch and 25% of the revenue. American lobster (*Homarus americanus*) was 14% of the catch by weight, but a greater portion of the revenue at 40%. Other commercially important species were spiny dogfish shark (*Squalus acanthias*), pollock (*Pollachius virens*), Atlantic herring, bluefin tuna (*Thunnus thynnus*), American plaice (*Hippoglossoides platessoides*), white hake (*Urophycis tenuis*), yellowtail flounder, and shrimp.

Commercial fishing in Massachusetts generated between $206 and $306 million in revenue per year between 1990 and 2000 (personal communication, National Marine Fisheries Service, Fisheries Statistics and Economics Division, Silver Spring, MD, 2002). Tables G1-5 and G1-6 show the pounds harvested in Massachusetts and the revenue generated for commercial fisheries from 1990 to 2000. Sea scallop is the most important commercial species by revenue, constituting 5% of the catch and 25% of the revenue. American lobster was 6% of the catch and 22% of the revenue. Atlantic herring was 17% of the catch but only 1% of the revenue. Atlantic cod was 14% of the catch and 11% of the revenue. Other commercially important species are goosefish (*Lophius americanus*), bluefin tuna, winter flounder, yellowtail flounder, spiny dogfish shark, skates (Rajidae), and ocean quahog clam.

Table G1-3: Commercial Fishing Landings in New Hampshire, 1990-2000 (pounds)

Species	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	Total
Alewife			9,802	2,676					25,994			38,472
Bass, striped	37									33		70
Bluefish	197,075	127,197	228,048	162,622	275,260	187,006	159,833	62,524	16,691	12,129	23,927	1,452,312
Bonito, Atlantic						25						25
Butterfish	1,207	472	151		4,975	283	285	731	8,269	722	7,335	24,430
Clam, Atlantic surf	9,010								1,088			10,098
Cod, Atlantic	3,774,455	4,649,553	3,608,230	2,961,523	3,014,581	2,764,418	2,789,942	2,003,171	1,490,755	350,017	1,756,330	29,162,975
Crab, Atlantic rock						24	118					142
Crab, green			3,515									3,515
Crab, jonah					4,500			828,403	571,780	207,199	518,093	2,129,975
Crabs	206,616	42,500	254,091	170,828	232,014	120,888	22,395	298,544	187,175	457,728	1,046	1,993,825
Cunner					367	816	576	98	129	58	78	2,122
Cusk	127,928	79,864	158,833	67,401	87,000	102,772	121,230	107,783	72,278	40,863	81,181	1,047,133
Dory, American john					3							3
Eel, American			285	1,384					423			2,092
Eel, conger	502	3	74			65	39	1,555	103			2,341
Finfishes unc bait and animal food[a]	151,625	395,365	77,456			130,492	43		710			755,691
Finfishes unc for food[a]	3,309	1,162	30	5,155	408,738	144,750	234,791	115,236	300,714	110,101	500	1,324,486
Finfishes unc spawn[a]	210	527	60	1,083								1,880
Flatfish	121	55			2,004				37			2,217
Flounder, summer	20	87	14									121
Flounder, window-pane	7,720	11,795	4,070	4,093	1,713	1,760	915	242	387	890	1,656	35,241
Flounder, winter	184,306	161,841	125,714	85,869	80,684	63,729	61,857	30,429	29,878	14,659	32,276	871,242
Flounder, witch	71,162	61,788	57,481	59,653	56,106	40,099	34,230	35,137	37,944	42,109	104,717	600,426
Flounder, yellowtail	180,150	196,817	129,435	91,901	101,815	124,764	139,655	89,144	61,683	95,999	192,552	1,403,915
Goose-fish	265,089	249,677	266,296	299,776	557,014	935,609	996,702	939,124	820,732	1,385,138	1,872,520	8,587,677
Haddock	36,057	40,643	26,031	19,279	19,129	34,245	24,118	29,988	44,132	73,579	134,301	481,502
Hagfishes								8,196				8,196
Hake, Atlantic red/white	343,565	271,280	23,231	8,881	15,068	11,294	30,511	36,629	6,600	13,153	30,545	790,757
Hake, red	298	834	48,985	46,455	67,312	31,909		6		1,429		197,228
Hake, silver	227,073	172,558	185,188	141,909	202,935	194,300	242,859	327,637	108,042	243,807	358,296	2,404,604
Hake, white	1,521	154,323	632,807	288,419	539,539	481,092	305,029	284,588	193,670	630,078	705,446	4,216,512
Halibut, Atlantic	848	1,133	858	453	210	802	924	2,395	1,566	2,523	9,552	21,264
Herring, Atlantic	368,000	381,070	562,413	774,292	435,200	323,894	33,655	152,431	260,463	2,442,736	5,581,880	11,316,034
Lobster, American	1,658,200	1,802,035	1,529,292	1,693,347	1,650,751	1,834,794	1,632,829	1,414,368	1,194,653	1,380,714	1,157,941	16,948,924
Lumpfish						48	1,002	7,476	35			8,561
Mackerel, Atlantic	49,645	13,659	102,264	44,898	47,990	45,812	27,784	10,539	18,985	21,350	7,620	390,546
Mantis shrimps										236		236

Table G1-3: Pounds of Commercial Fishing Landings in New Hampshire, 1990–2000 (pounds) (cont.)

Species	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	Total
Menhaden, Atlantic	264,500	204,000	25,920	3,710					9			498,139
Mussel, blue								115				115
Plaice, American	206,520	180,850	352,115	326,775	321,442	294,089	347,054	246,328	213,684	178,326	185,612	2,852,795
Pollock	1,699,460	1,117,535	1,162,159	1,223,348	1,001,842	842,534	818,130	1,290,123	1,412,644	1,640,980	1,337,440	13,546,195
Pout, ocean	5,396	5,577	12,228	5,130	2,016	1,830	3,162	2,525	1,061	89	278	39,292
Redfish or ocean perch	31,784	42,491	11,953	16,228	18,609	19,287	14,774	10,755	16,988	44,897	47,992	275,758
Sandworms								599				599
Scallop sea									6,887			8,906
Scups or porgies				67								67
Sea raven						8,884		6,997		227	65	16,173
Sea urchins	59,800	47,797	102,494	46,163	12,117	4,074	10,410	18,337		5,041	792	307,025
Shad, American	38,206	18,924	9,903	6,549	28,226	30,561	35,561	25,436	15,169	3,674	5,942	218,151
Shark, porbeagle	640	125	397						7,804	4,024	3,137	16,127
Shark, spiny dogfish	185,175		402,184	1,641,614	2,597,792	2,106,255	1,079,523	1,009,140	1,893,425	1,242,893	2,334,497	14,492,498
Sharks	2,173	8,868	5,566	6,928	11,988	11,602	10,463	6,720	869	1,413	97	66,687
Sheepshead											63	63
Shellfish										69,831	82,635	152,466
Shrimp, marine other	986,194	459,141	220,733	972,705	1,148,571	1,658,588	1,692,017	1,256,950	887,059	375,861	467,956	10,125,775
Silver-sides				8,888								8,888
Skates	23,140	27,371	22,223	20,837	81,877	54,486	44,688	37,345	42,163	57,997	84,709	496,836
Smelt, rainbow			36				346					382
Snails (conchs)						4,544	5,867	19,620	13,449	2,504	274	46,258
Squid, longfin							12					12
Squid, northern shortfin	128	208	446		20	3	205	861	6,075	4,518	641	13,105
Squids	810	6,838	4,555	5,402	4,363	896	3,202	1,626	234			27,926
Sturgeons	140											140
Tautog	5	63	4									72
Tilefish			172	36	50					26		284
Tuna, bluefin	62,194	267,853	182,554	128,603	138,323	104,648	106,505	143,024	170,290	79,480	8,171	1,391,645
Tuna, yellowfin						462						462
Wolffish, Atlantic	25,409	17,852	22,965	19,117	27,980	40,005	34,749	31,772	29,703	18,606	21,674	289,832
Total	11,457,423	11,221,731	10,573,261	11,363,997	13,200,566	12,758,694	11,068,246	10,895,712	10,172,429	11,257,637	17,159,767	131,129,463

 [a] Note: "All annual and monthly landing summaries will return only nonconfidential landing statistics. Federal statutes prohibit public disclosure of landings (or other information) that would allow identification of the data contributors and possibly put them at a competitive disadvantage. Most summarized landings are nonconfidential, but whenever confidential landings occur they have been combined with other landings and usually reported as "finfishes, unc" (unclassified) or "shellfishes, unc." Total landings by state include confidential data and will be accurate, but landings reported by individual species may, in some instances, be misleading due to data confidentiality (Personal communication, National Marine Fisheries Service, Fisheries Statistics and Economics Division, Silver Spring, MD, 2002)."

Table G1-4: Revenue from Commercial Landings in New Hampshire, 1990–2000

Species	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	Total
Alewife			$4,900	$576					$3,795			$9,271
Bass, striped	$65									$81		$146
Bluefish	$52,048	$33,799	$61,352	$62,866	$76,030	$57,231	$44,134	$16,529	$5,794	$5,302	$9,493	$424,578
Bonito, Atlantic						$15						$15
Butterfish	$559	$283	$117		$998	$89	$84	$479	$7,434	$474	$4,095	$14,612
Clam, Atlantic surf	$4,240								$3,264			$7,504
Cod, Atlantic	$2,487,035	$3,714,543	$3,169,995	$2,673,803	$2,708,000	$2,469,878	$2,143,393	$1,635,941	$1,549,945	$394,173	$1,807,127	$24,753,833
Crab, Atlantic rock						$13	$60					$73
Crab, green			$1,177									$1,177
Crab, jonah					$1,800			$386,204	$282,042	$121,184	$310,854	$1,102,084
Crabs	$76,721	$13,600	$93,075	$63,938	$92,297	$47,209	$12,003	$166,294	$96,485	$249,232	$621	$911,475
Cunner					$253	$368	$211	$61	$51	$12	$11	$967
Cusk	$60,516	$41,960	$79,086	$34,970	$48,458	$58,651	$67,616	$55,859	$41,031	$28,480	$44,975	$561,602
Dory, American john					$3							$3
Eel, American			$430	$2,076					$486			$2,992
Eel, conger	$50	$1	$23			$12	$6	$175	$2			$269
Finfishes unc bait and animal food[a]	$12,130	$31,665	$7,571			$12,333	$43		$42			$63,784
Finfishes unc for food[a]	$2,498	$835	$22	$642	$36,271	$14,414	$22,813	$11,506	$35,866	$10,505	$48	$135,420
Finfishes unc spawn[a]	$21	$265	$36	$958								$1,280
Flatfish	$97	$14			$2,443				$37			$2,591
Flounder, summer	$16	$92	$12									$120
Flounder, windowpane	$1,682	$2,811	$1,548	$1,851	$802	$566	$385	$126	$213	$643	$1,186	$11,813
Flounder, winter	$162,050	$171,968	$134,087	$88,709	$87,114	$69,353	$67,904	$38,368	$32,873	$15,948	$31,077	$899,451
Flounder, witch	$133,673	$103,683	$81,856	$92,267	$92,459	$70,496	$59,889	$71,419	$64,026	$59,375	$123,949	$953,092
Flounder, yellowtail	$141,619	$182,027	$120,017	$94,436	$116,499	$137,533	$129,947	$110,828	$70,931	$92,821	$194,863	$1,391,521
Goosefish	$138,990	$172,399	$139,246	$167,584	$390,528	$741,098	$806,147	$801,504	$670,769	$1,714,930	$2,714,813	$8,458,008
Haddock	$46,939	$56,015	$34,859	$32,039	$29,983	$50,185	$30,081	$37,153	$59,408	$103,640	$186,665	$666,967
Hagfishes								$2,131				$2,131
Hake, Atlantic red/white	$126,680	$95,079	$6,469	$1,972	$3,366	$2,541	$6,250	$7,242	$1,418	$2,540	$5,521	$259,078
Hake, red	$136	$281	$8,381	$9,219	$13,095	$2,760		$7		$100		$33,979
Hake, silver	$76,105	$59,863	$79,984	$70,214	$79,194	$75,955	$96,832	$112,782	$41,198	$107,622	$130,331	$930,080
Hake, white	$780	$85,015	$269,694	$135,008	$285,078	$251,888	$159,708	$159,680	$131,000	$439,574	$327,459	$2,244,884
Halibut, Atlantic	$1,154	$1,789	$2,484	$1,331	$674	$2,969	$2,846	$6,112	$3,361	$4,532	$14,867	$42,119
Herring, Atlantic	$17,680	$25,512	$50,681	$87,085	$44,448	$34,506	$3,050	$14,237	$23,754	$148,278	$306,139	$755,370
Lobster, American	$4,048,800	$4,934,205	$5,033,198	$5,567,109	$5,566,282	$6,655,660	$6,563,641	$5,545,775	$4,702,353	$5,916,818	$4,933,439	$59,467,280
Lumpfish						$5	$116	$781	$2			$904
Mackerel, Atlantic	$14,638	$5,550	$25,582	$20,225	$21,117	$13,360	$7,982	$4,982	$7,906	$8,611	$4,039	$133,992
Mantis shrimps										$826		$826

Table G1-4: Revenue from Commercial Landings in New Hampshire, 1990-2000 (cont.)

Species	Year											Total
	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	
Menhaden, Atlantic	$5,880	$8,160	$1,495	$557					$5			$16,097
Mussel, blue								$12				$12
Plaice, American	$207,794	$168,885	$314,514	$350,782	$385,216	$350,783	$352,272	$301,619	$287,411	$200,705	$177,285	$3,097,266
Pollock	$870,009	$616,293	$743,414	$837,745	$803,698	$725,822	$578,714	$780,992	$969,587	$1,429,949	$1,045,078	$9,401,301
Pout, ocean	$912	$870	$2,083	$955	$343	$303	$433	$354	$77	$24	$28	$6,382
Redfish or ocean perch	$19,097	$23,444	$6,750	$9,606	$11,685	$11,835	$7,376	$6,848	$9,502	$20,416	$18,892	$145,451
Sandworms								$2,138				$2,138
Scallop, sea					$772	$1,386	$1,271	$8,077	$50,824			$62,330
Scups or porgies				$71								$71
Sea raven						$1,285		$749		$11	$7	$2,052
Sea urchins	$22,876	$33,457	$49,589	$26,501	$6,648	$3,359	$11,604	$16,870		$4,852	$1,109	$176,865
Shad, American	$6,665	$4,535	$2,429	$1,764	$8,850	$7,789	$9,039	$4,794	$3,605	$530	$642	$50,642
Shark, porbeagle	$709	$90	$203						$4,851	$1,812	$1,873	$9,538
Shark, spiny dogfish	$21,916		$50,638	$252,983	$393,548	$397,812	$189,537	$145,723	$350,488	$205,577	$604,980	$2,613,202
Sharks	$2,273	$6,920	$3,773	$4,781	$8,531	$7,937	$5,279	$3,099	$470	$566	$127	$43,756
Sheepshead											$19	$19
Shellfish										$453,741	$482,436	$936,177
Shrimp, marine other	$760,886	$449,781	$252,492	$932,247	$818,524	$1,420,581	$1,274,983	$1,079,186	$790,976	$281,570	$374,583	$8,435,809
Silversides				$4,616								$4,616
Skates	$1,993	$2,682	$2,027	$2,491	$20,706	$11,833	$12,054	$8,500	$8,009	$9,670	$12,987	$92,952
Smelt, rainbow			$43				$395					$438
Snails (conchs)						$1,635	$1,707	$6,363	$4,192	$630	$139	$14,666
Squid, longfin							$11					$11
Squid, northern shortfin	$49	$62	$140		$5	$2	$76	$252	$2,850	$1,611	$302	$5,349
Squids	$211	$1,735	$1,298	$1,507	$1,084	$333	$941	$189	$58			$7,356
Sturgeons	$117											$117
Tautog	$3	$36	$2									$41
Tilefish			$292	$29	$69					$32		$422
Tuna, bluefin	$539,490	$2,232,641	$1,208,612	$1,299,083	$1,231,522	$1,197,550	$849,403	$1,012,606	$856,249	$498,147	$70,562	$10,995,865
Tuna, yellowfin						$1,183						$1,183
Wolffish, Atlantic	$9,075	$7,309	$8,851	$6,559	$9,439	$14,885	$11,732	$12,041	$11,684	$6,186	$7,973	$105,734
Total	$10,076,877	$13,290,154	$12,054,527	$12,941,155	$13,397,832	$14,925,401	$13,531,968	$12,576,587	$11,186,324	$12,541,730	$13,950,594	$140,473,149

[a] Note: "All annual and monthly landing summaries will return only nonconfidential landing statistics. Federal statutes prohibit public disclosure of landings (or other information) that would allow identification of the data contributors and possibly put them at a competitive disadvantage. Most summarized landings are nonconfidential, but whenever confidential landings occur they have been combined with other landings and usually reported as **"finfishes, unc"** (**unclassified**) or **"shellfishes, unc."** Total landings by state include confidential data and will be accurate, but landings reported by individual species may, in some instances, be misleading due to data confidentiality (Personal communication, National Marine Fisheries Service, Fisheries Statistics and Economics Division, Silver Spring, MD, 2002)."

Table G1-5: Commercial Fishery Landings in Massachusetts, 1990-2000 (pounds)

Species	Year											Total
	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	
Alewife	20,700	20,300	18,700	18,900								78,780
Amberjack								180		48		139
Argentines					18	49	1	1		10		10
Bass, striped	159,729	235,238	237,059	266,573	200,000	751,477	695,935	784,892	810,112	766,237	796,159	5,703,411
Bluefish	1,204,033	756,157	829,586	636,205	1,197,661	558,003	906,032	435,781	363,885	411,074	282,356	7,580,773
Bonito, Atlantic	3,734	4,285	87,063	17,263	63,547	39,487	13,750	25,642	24,161	29,724	996	309,652
Butterfish	111,501	27,421	13,030	49,127	58,224	48,472	38,162	67,399	50,630	162,770	75,552	702,288
Catfishes and bullheads					9							9
Clam, arctic surf (Stimpson)	303,240											303,240
Clam, Atlantic jackknife	21,280	24,480	79,968	326,128					35			451,891
Clam, Atlantic surf	1,723,061	2,606,514	2,109,918	2,312,560	6,823,403	6,438,392	2,300,262	1,544,790	1,670,346	880,209	734,052	29,143,507
Clam, ocean quahog				4,847,629	158,206	16,717,424	17,512,360	20,437,600	19,188,980	16,530,140	12,397,360	107,789,699
Clam, quahog	1,100,341	1,001,077	1,006,675	1,098,420								4,206,513
Clam, softshell	967,629	1,148,745	1,419,644	1,348,920								4,884,938
Clams or bivalves	72,912	840,591	49,904		102				4,955			968,464
Cod, Atlantic	72,199,655	62,453,071	42,273,472	36,508,334	27,029,568	21,294,025	23,221,482	22,189,499	20,018,151	18,679,722	19,804,122	365,671,101
Crab, Atlantic rock							265	937		105,792		106,994
Crab, cancer							387			48		435
Crab, deepsea red								2,427,926			5,252,739	7,680,665
Crab, green	800	700	1,000									2,500
Crab, horseshoe		2,040			153	211	275	133	159	14,430		17,401
Crab, jonah					1,327,393	1,077,922	1,204,690	2,696,951	1,118,194	1,739,112	1,358,571	10,522,833
Crabs	4,598,886	4,910,837	3,822,373	4,479,872		110,528	3,026	2,340	1,347,403	3,603,096	3,864,464	26,742,825
Cunner		15	66	573	479	809	395	664	1,160	434	739	5,334
Cusk	1,615,095	1,972,011	1,569,185	1,081,184	770,503	771,600	461,832	301,435	268,149	178,328	140,407	9,129,729
Dolphin	3,688	3,475	4,255	797	1,023	4,398	3,959	8,056	3,808	705	4,619	38,783
Dory, American john					101	1,825	460	4	1,153	1,244		4,787
Eel, American	27,791	23,475	35,798	27,693		30	19	304		363		115,473
Eel, conger	747	43	350	2,216	151	872	571	208	1,060	2,611	1,168	9,997
Escolar										976		976
Finfishes, groundfishes, other	391										2	393
Finfishes, pelagic, other										34	84	118

Table G1-5: Commercial Fishery Landings in Massachusetts, 1990-2000 (pounds) (cont.)

Species	Year											Total
	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	
Finfishes unc bait and animal food[a]	31,631	4,938	112,574	49,993	9,833	8,080			28,100			245,149
Finfishes unc for food[a]	209,142	208,339	120,362	50,249	431,341	131,618	39,551	11,869	8,344	6,591	6,265	1,223,671
Finfishes unc general[a]	1,569,000							2,745,943			20,006	4,334,949
Finfishes unc spawn[a]		95						9				104
Flatfish	111,905	150,650	167,102	112,377	31,096	20,207	15,255	12,837	1,803	1,572	7,980	632,784
Flounder, summer	628,988	1,121,811	1,383,283	954,463	1,031,203	1,128,120	800,729	745,171	709,387	812,540	788,998	10,104,693
Flounder, windowpane	3,659,143	7,676,566	4,275,610	3,194,349	923,574	1,588,687	2,017,768	980,892	941,919	109,406	300,339	25,668,253
Flounder, winter	11,129,732	12,406,600	9,982,728	8,657,466	5,694,288	6,291,720	8,281,798	9,309,941	8,597,510	7,430,610	8,991,331	96,773,724
Flounder, witch	1,548,640	1,728,640	2,120,628	2,484,740	2,411,680	2,454,202	2,092,391	1,673,440	1,976,581	2,322,016	2,901,059	23,714,017
Flounder, yellowtail	25,579,045	13,104,026	10,527,616	7,000,662	6,305,520	3,878,007	4,407,382	4,551,397	6,596,358	7,373,272	12,433,647	101,756,932
Goosefish	16,978,441	15,592,744	20,952,392	26,482,563	27,273,925	31,744,000	27,137,617	27,064,088	27,618,917	26,446,684	20,887,818	268,179,189
Grenadiers								10				10
Groupers						415				18		433
Haddock	4,890,381	3,453,535	4,376,156	1,582,906	566,848	727,534	997,606	2,236,415	4,258,730	4,948,032	6,871,363	34,909,506
Hagfishes				869,386	2,372,037	3,133,716	3,415,107		1,261,403	2,344,004	5,602,082	18,997,735
Hake, Atlantic red/white					650	8		57				715
Hake, offshore silver						78				11,589		11,667
Hake, red	1,593,565	1,573,577	1,806,616	1,512,702	1,407,159	334,964	861,155	689,398	348,853	406,427	395,904	10,930,320
Hake, silver	8,780,783	8,725,814	7,939,837	5,456,579	4,699,870	2,829,976	2,734,106	2,850,162	2,797,494	4,274,165	4,934,030	56,022,816
Hake, white	4,649,732	4,678,307	5,557,614	4,556,670	3,052,208	3,364,624	2,488,795	1,372,405	1,953,474	2,077,960	1,997,572	35,749,361
Halibut, Atlantic	12,292	21,786	10,347	10,446	7,821	10,786	9,815	5,595	8,736	10,474	6,516	114,614
Halibut, Greenland										2		2
Herring, Atlantic	61,917,269	47,852,491	50,650,281	24,719,975	16,106,401	31,388,855	48,239,980	53,404,269	74,672,252	23,756,110	9,614,704	442,322,587
King, whiting			150		110	2	1,214	58	115	130		1,779
Leatherjackets				12	85	502	1,934	1,890	1,619	406	407	6,855
Lobster, American	17,054,434	16,528,168	15,823,077	14,336,032	16,100,264	15,771,981	15,330,377	15,092,014	13,278,726	15,533,953	14,613,665	169,462,691
Lumpfish						70	200			58		328
Mackerel, Atlantic	1,417,190	307,803	972,757	434,458	757,444	616,681	899,069	1,236,166	2,333,402	1,330,581	479,268	10,784,819
Mackerel, king and cero	21	1,214	234		81	198	4	685	77	254		2,768
Mackerel, Spanish	6,585	19,698	608	5	3,273			15	71	2,407		32,662
Menhaden, Atlantic	1,361,900	6,326,300	6,606,593	1,332,000		61,000	8,500			904,200		16,600,493

Table G1-5: Commercial Fishery Landings in Massachusetts, 1990-2000 (pounds) (cont.)

Species	Year											Total
	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	
Mussel, blue	5,479,765		5,509,501	1,722,705								12,711,971
Octopus							8					8
Opah						640				88		728
Oyster, eastern	31,388	33,085	48,580	42,185								155,241
Perch, white	27,468	7,312	5,845	3,206	161	129	1,699	311	665	620		47,416
Periwinkles									52	2		54
Plaice, American	2,184,670	4,308,396	6,737,235	5,838,508	4,628,509	4,884,640	4,586,529	4,191,964	4,204,038	3,376,840	3,625,243	48,566,572
Pollock	13,611,536	9,144,556	7,060,004	5,595,699	4,174,315	3,631,827	3,079,141	4,681,561	6,166,881	4,838,741	3,593,979	65,578,240
Pout, ocean		1,634,114	392,221	198,304	116,592	82,708	17,498	10,589	7,898	9,513	10,482	2,479,919
Redfish or ocean perch	698,247	618,890	945,093	742,092	598,780	657,981	479,518	290,387	345,604	327,306	292,706	5,996,604
Scallop, bay	254,389	190,847	564,821	136,026		24	1,339					1,147,446
Scallop, sea	22,734,370	22,015,091	19,398,149	8,913,285	6,537,408	7,706,117	8,555,955	7,093,022	5,750,901	12,270,619	16,174,736	137,149,653
Sculpins		4,810		265		880	5	150				6,110
Scups or porgies	1,533,459	1,219,134	1,444,682	1,224,625	780,550	683,943	961,997	1,491,570	959,519	661,581	355,403	11,316,463
Sea bass, black	435,928	244,169	43,123	39,459	20,800	41,525	39,646	91,005	280,696	573,545	625,902	2,435,798
Sea cucumber						135						135
Sea raven		2,663	1,364	10	82	3			175	627		4,924
Sea urchins		320	2,869	733,682	562,594	172,407	102,772	334,456	407,904	283,468		2,600,472
Searobins		12,000	130	74	30	167	32	2	950	11		13,396
Shad, American	5,600	638	308	419	286	441	134	570	1,015	223	268	9,902
Shad, American buck	5		4									9
Shad, American roe						13		182	750			945
Shark, bigeye thresher								158				158
Shark, bignose								13				13
Shark, blue	136					246						382
Shark, dogfish	17,806,480	14,488,910	18,375,718	26,830,777	101,115	845,963	2,548	806	1,148	92	311	78,451,228
Shark, longfin mako	129	4,736	19,998						924			28,427
Shark, makos	283											283
Shark, night						229		55				284
Shark, nurse			4									4
Shark, porbeagle	22,867	13,972	3,179	2,537	1,592	5,738	3,472	3,053	5,816	2,356		64,582
Shark, sand tiger			560									560
Shark, shortfin mako	33,567	57,586	69,924	97,105	87,047	119,377	53,886	51,041	40,208	22,582	22,675	654,998

Table G1-5: Commercial Fishery Landings in Massachusetts, 1990-2000 (pounds) (cont.)

Species	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	Total
Shark, smooth dogfish	275,000	4,400	9,700		12,795	45	6	11,245				313,191
Shark, spiny dogfish					23,113,049	27,914,222	26,959,238	21,819,727	25,033,929	14,929,804	5,761,654	145,531,623
Shark, thresher				1,090	1,529	791	1,263	421	719	107		7,462
Shark, tiger								14				14
Sharks	75,294	24,507	30,645	25,793	17,798	22,896	19,693	47,252	18,747	8,885	45,507	337,017
Sheepshead										90		90
Shellfish	1,424,444	6,265,148	1,506,909	741,005	636,657	114,434	105,620				342,817	11,137,034
Shrimp, brown			3			365	6,717					7,085
Shrimp, marine, other	2,189,979	1,626,263	643,027	662,113	842,014	1,494,147	1,294,914	709,278	491,760	111,876	243,323	10,308,694
Silversides										3		3
Skates	12,658,620	12,557,364	13,058,290	13,488,726	14,685,991	6,458,124	19,899,001	8,684,294	14,177,490	10,619,501	14,368,941	140,656,342
Smelt, rainbow		13,200	1,200	1,200								16,600
Snails (conchs)					70,258	213,450	184,931	156,774	197,739	181,328	192,183	1,196,663
Spot				30					60			90
Squid, longfin	1,414,992	1,959,821	681,688	1,390,484	934,101	1,420,698	1,135,166	1,326,198	1,397,935	2,691,001	2,661,560	17,013,644
Squid, northern shortfin	83	200	1,855	1,886	724	137		1,156	1,965,665	1,007,436	15,245	2,994,387
Squids	57,409	23,837	8,327	42,325	36,883	30,960	113,039	343,225	39,572	107,433	14,080	817,090
Sturgeons	562	1,063	114	481	60	444						2,724
Swordfish	2,655,634	1,811,161	1,872,042	1,601,422	1,412,178	1,749,998	1,143,634	1,078,951	1,264,329	1,174,772	1,376,146	17,140,267
Tautog	289,074	354,346	292,291	160,336	37,399	35,298	32,579	64,275	91,424	75,685	96,001	1,528,708
Tilefish	15,531	2,436	6,206	31,844	5,982	1,926	516	821	8,204	3,924	160	77,550
Toadfishes											100	100
Tuna, albacore	39,470	12,860	14,203	7,214	31,920	30,507	21,337	23,054	5,366	6,309	10,741	202,981
Tuna, bigeye	71,058	178,935	129,134	196,868	122,366	288,048	187,354	183,847	120,671	77,528	122,331	1,678,140
Tuna, bluefin	1,753,140	1,335,841	1,352,007	1,395,955	1,352,480	1,270,756	1,485,666	1,747,076	1,660,103	1,872,165	2,094,389	17,319,578
Tuna, little tunny		7,500	5,006	2,419				2,353	4,869	6,536	1,274	29,957
Tuna, skipjack	198	1,484,540	308,644	56		148						1,793,586
Tuna, yellowfin	189,455	2,173,357	1,145,050	21,365	22,261	56,786	69,951	58,290	24,959	20,520	25,596	3,807,590
Tunas	13,307	420	705	56	1,045	1,539	3,223	6,317	4,648	1,398	1,905	34,563
Wahoo		103	1,102			75	47		51	16		1,394
Weakfish	1,720	1,912	3,033	1,080		535	86	55	410	2,550	527	11,908
Wolffish, Atlantic	589,073	698,546	649,859	710,304	711,928	754,099	584,870	500,334	488,376	400,747	294,985	6,383,121
Total	335,841,904	302,052,566	279,288,959	279,425,468	188,476,531	213,997,116	237,279,246	229,915,320	257,438,385	198,877,420	187,938,490	2,660,531,405

a Note: "All annual and monthly landing summaries will return only nonconfidential landing statistics. Federal statutes prohibit public disclosure of landings (or other information) that would allow identification of the data contributors and possibly put them at a competitive disadvantage. Most summarized landings are nonconfidential, but whenever confidential landings occur they have been combined with other landings and usually reported as "finfishes, unc" (unclassified) or "shellfishes, unc." Total landings by state include confidential data and will be accurate, but landings reported by individual species may, in some instances, be misleading due to data confidentiality (Personal communication, National Marine Fisheries Service, Fisheries Statistics and Economics Division, Silver Spring, MD, 2002)."

Table G1-6: Revenue from Commercial Landings in Massachusetts, 1990-2000

Species	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	Total
Alewife	$1,976	$2,496	$2,244	$2,268				$360				$9,344
Amberjack					$6	$40	$1	$1		$15		$67
Argentines										$28		$28
Bass, striped	$310,460	$482,024	$335,480	$516,309	$302,000	$676,428	$960,750	$1,154,243	$1,223,245	$1,196,851	$2,289,730	$9,447,520
Bluefish	$251,555	$120,570	$139,270	$259,629	$221,219	$146,545	$228,577	$96,321	$157,948	$171,015	$104,692	$1,897,341
Bonito, Atlantic	$2,061	$2,432	$11,336	$13,277	$46,470	$29,098	$9,194	$19,274	$21,282	$36,338	$2,042	$192,804
Butterfish	$61,326	$11,716	$6,016	$21,674	$21,852	$20,527	$10,251	$29,334	$22,193	$80,695	$38,388	$323,972
Catfishes and bullheads					$3							$3
Clam, arctic surf (Stimpson)	$271,350											$271,350
Clam, Atlantic jackknife	$78,900	$84,125	$208,755	$240,365					$28			$612,173
Clam, Atlantic surf	$1,089,042	$1,362,156	$1,187,246	$1,813,213	$6,106,751	$5,511,794	$2,025,273	$1,312,263	$1,188,055	$653,357	$581,102	$22,830,252
Clam, ocean quahog				$3,069,232	$57,583	$6,827,627	$7,316,842	$8,589,407	$8,048,112	$6,904,870	$5,234,810	$46,048,483
Clam, quahog	$5,457,003	$4,122,098	$4,416,757	$4,098,964								$18,094,822
Clam, softshell	$4,538,252	$5,575,514	$7,398,251	$7,748,123								$25,260,140
Clams or bivalves	$58,043	$684,550	$38,564		$20				$2,481			$783,658
Cod, Atlantic	$46,295,857	$50,649,672	$35,996,894	$32,516,426	$25,279,616	$20,303,945	$19,880,183	$19,111,274	$20,819,477	$20,871,132	$20,651,479	$312,375,955
Crab, Atlantic rock							$135	$357		$49,221		$49,713
Crab, cancer							$193			$24		$217
Crab, deepsea red								$1,114,117			$3,636,698	$4,750,815
Crab, green	$240	$210	$700									$1,150
Crab, horseshoe					$377	$75	$119	$83	$156	$7,929		$8,943
Crab, jonah					$569,133	$667,133	$663,236	$1,318,895	$557,411	$902,110	$736,339	$5,414,257
Crabs	$2,375,745	$2,348,025	$1,727,675	$2,052,841		$134,935	$1,503	$2,546	$544,790	$1,639,076	$2,082,330	$12,909,466
Cunner		$6	$12	$141	$193	$241	$111	$236	$304	$161	$216	$1,621
Cusk	$720,304	$958,183	$762,352	$533,387	$434,208	$449,920	$274,105	$175,084	$186,894	$138,682	$87,446	$4,720,565
Dolphin	$4,230	$3,086	$4,909	$1,693	$1,539	$4,349	$6,427	$6,627	$5,508	$1,743	$8,501	$48,612
Dory, American john					$113	$822	$193	$3	$296	$739		$2,166
Eel, American	$35,666	$28,702	$54,245	$33,632				$380		$182		$152,834
Eel, conger	$1,367	$16	$68	$2,847	$31	$456	$118	$93	$510	$1,516	$563	$7,585
Escolar											$1,130	$1,130
Finfishes, groundfishes, other	$391										$1	$392

Table G1-6: Revenue from Commercial Landings in Massachusetts, 1990-2000 (cont.)

Species	Year											Total
	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	
Finfishes, pelagic, other										$101	$223	$324
Finfishes unc bait and animal food	$2,583	$1,381	$7,202	$3,358	$776	$564			$2,333			$18,197
Finfishes unc for food	$123,477	$167,516	$87,380	$43,431	$238,329	$85,564	$29,260	$7,251	$3,870	$3,237	$3,903	$793,218
Finfishes unc general	$182,876							$755,209			$25,131	$963,216
Finfishes unc spawn		$46						$40				$86
Flatfish	$112,108	$132,066	$154,807	$106,080	$33,229	$24,109	$17,455	$14,957	$2,125	$1,517	$8,145	$606,598
Flounder, summer	$1,408,670	$1,727,449	$2,032,422	$2,064,498	$1,907,260	$2,502,321	$1,701,550	$1,533,127	$1,386,608	$1,635,506	$1,443,860	$19,343,271
Flounder, windowpane	$1,478,214	$4,205,901	$2,818,513	$2,188,441	$547,793	$995,484	$857,876	$509,977	$365,004	$34,963	$91,173	$14,093,339
Flounder, winter	$13,343,566	$14,986,080	$12,101,594	$12,076,208	$8,637,768	$9,404,437	$11,765,726	$12,555,518	$11,696,023	$9,672,315	$8,898,326	$125,137,561
Flounder, witch	$2,714,961	$2,580,414	$2,789,942	$3,853,068	$3,862,469	$4,209,763	$3,583,477	$2,868,526	$3,256,831	$3,414,595	$3,821,671	$36,955,717
Flounder, yellowtail	$23,039,450	$13,953,565	$11,960,089	$9,161,035	$7,545,101	$5,585,430	$6,541,012	$7,092,360	$9,051,857	$8,496,328	$12,510,009	$114,936,236
Goosefish	$7,585,652	$9,698,380	$8,232,544	$9,800,666	$14,411,107	$20,049,943	$15,863,372	$15,377,104	$15,842,804	$21,871,872	$24,120,969	$162,854,413
Grenadiers								$10				$10
Groupers						$440				$36		$476
Haddock	$5,353,690	$3,837,254	$4,721,243	$2,157,251	$798,583	$990,612	$1,178,641	$2,455,042	$5,411,740	$6,517,286	$8,908,612	$42,329,954
Hagfishes				$234,639	$672,733	$865,459	$945,328		$326,704	$667,811	$1,471,539	$5,184,213
Hake, Atlantic red/white					$469	$8		$22				$499
Hake, offshore silver						$40				$11,422		$11,462
Hake, red	$302,813	$323,401	$350,571	$291,786	$346,453	$79,502	$187,634	$145,136	$98,683	$134,134	$98,183	$2,358,296
Hake, silver	$2,260,496	$2,626,274	$2,680,547	$1,804,195	$1,624,163	$1,025,444	$935,348	$1,141,722	$1,419,237	$2,640,780	$2,173,212	$20,331,418
Hake, white	$1,872,620	$2,002,978	$2,500,236	$2,033,211	$1,646,550	$2,184,550	$1,492,871	$921,584	$1,459,152	$1,544,366	$1,041,993	$18,700,111
Halibut, Atlantic	$23,052	$43,176	$23,641	$17,669	$18,140	$27,717	$24,931	$14,144	$21,385	$23,957	$19,190	$257,002
Halibut, Greenland										$1		$1
Herring, Atlantic	$2,771,700	$2,176,670	$2,367,588	$1,148,850	$733,507	$1,402,941	$2,233,927	$2,657,904	$3,922,494	$1,260,226	$604,066	$21,279,873
King whiting			$56		$44	$2	$1,168	$69	$96	$111		$1,546
Leather-jackets				$6	$45	$362	$1,395	$904	$1,313	$268	$337	$4,630
Lobster, American	$43,824,047	$46,389,972	$48,838,763	$43,106,462	$58,412,340	$55,787,476	$64,536,117	$61,980,355	$48,580,999	$66,770,985	$67,460,826	$605,688,342
Lumpfish						$15	$126			$28		$169

Table G1-6: Revenue from Commercial Landings in Massachusetts, 1990-2000 (cont.)

Species	Year											Total
	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	
Mackerel, Atlantic	$222,187	$92,657	$144,917	$112,106	$247,114	$180,075	$176,680	$518,832	$722,356	$338,114	$183,579	$2,938,617
Mackerel, king and cero	$17	$608	$118		$61	$324	$6	$1,100	$166	$474		$2,874
Mackerel, Spanish	$5,268	$9,852	$307	$4	$2,558			$19	$84	$3,532		$21,624
Menhaden, Atlantic	$57,086	$271,055	$263,749	$53,065		$2,745	$1,870			$36,168		$685,738
Mussel, blue	$1,874,055		$1,859,144	$1,009,308								$4,742,507
Octopus							$14					$14
Opah						$1,078				$154		$1,232
Oyster, eastern	$316,252	$287,930	$570,302	$278,306					$2			$1,452,792
Perch, white	$41,978	$9,748	$7,710	$4,343	$267	$144	$2,380	$454	$779	$1,079		$68,882
Periwinkles									$31	$1		$32
Plaice, American	$2,207,701	$3,981,730	$6,429,615	$6,629,740	$5,429,330	$6,404,579	$5,881,754	$5,731,852	$5,407,460	$4,223,372	$3,756,403	$56,083,536
Pollock	$6,740,597	$5,354,688	$4,616,044	$3,735,907	$3,230,555	$3,145,426	$2,062,066	$2,586,517	$3,998,778	$3,833,415	$2,705,310	$42,009,303
Pout, ocean		$186,530	$38,584	$24,397	$15,486	$11,378	$5,352	$4,168	$2,041	$2,128	$2,993	$293,057
Redfish or ocean perch	$367,693	$286,192	$392,914	$343,002	$359,127	$399,605	$310,026	$188,501	$200,246	$170,930	$136,736	$3,154,972
Scallop, bay	$1,682,509	$1,362,864	$4,056,005	$1,451,532		$180	$2,145					$8,555,235
Scallop, sea	$90,970,303	$93,233,723	$96,371,352	$54,617,754	$35,799,795	$40,748,009	$49,734,289	$47,124,160	$36,037,285	$70,334,650	$85,293,917	$700,265,237
Sculpins		$541		$106		$170	$2	$49				$868
Scups or porgies	$1,003,511	$745,008	$835,251	$1,041,525	$707,719	$959,469	$1,388,842	$2,013,431	$1,699,017	$773,811	$447,650	$11,615,234
Sea bass, black	$714,494	$517,239	$108,575	$98,976	$56,460	$104,467	$94,190	$216,288	$634,279	$961,186	$968,989	$4,475,143
Sea cucumber						$27						$27
Sea raven		$256	$326	$3	$8	$2			$26	$233		$854
Sea urchins		$144	$1,268	$338,829	$348,401	$135,809	$77,306	$279,756	$356,149	$292,643		$1,830,305
Searobins		$26,280	$36	$16	$4	$33	$4	$1	$114	$2		$26,490
Shad, American	$2,044	$149	$92	$251	$174	$106	$44	$172	$252	$28	$52	$3,364
Shad, American buck	$1			$1								$2
Shad, American roe						$32		$67	$117			$216
Shark, bigeye thresher								$200				$200
Shark, bignose								$9				$9
Shark, blue	$204					$221						$425
Shark, dogfish	$1,597,669	$1,145,153	$2,186,537	$3,541,555	$18,970	$114,654		$806	$1,553		$202	$8,607,099
Shark, longfin mako	$109	$3,476	$17,516				$2,035		$1,097	$132		$24,365
Shark, makos	$447											$447

Table G1-6: Revenue from Commercial Landings in Massachusetts, 1990-2000 (cont.)

Species	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	Total
Shark, night								$33				$148
Shark, nurse			$1									$1
Shark, porbeagle	$16,411	$12,783	$2,007	$1,714	$811	$3,335	$2,514	$2,139	$5,541	$2,154		$49,409
Shark, sand tiger			$105									$105
Shark, shortfin mako	$35,086	$52,286	$63,977	$87,233	$61,288	$94,604	$49,440	$45,473	$33,740	$20,644	$23,399	$567,170
Shark, smooth dogfish	$22,000	$450	$1,761		$4,220	$99	$2	$2,637				$31,169
Shark, spiny dogfish					$3,375,624	$5,299,126	$4,934,313	$3,118,850	$4,297,312	$2,316,803	$1,335,411	$24,677,439
Shark, thresher	$496			$775	$465	$289	$557	$216	$450	$5		$3,253
Shark, tiger								$95				$95
Sharks	$66,663	$18,456	$19,473	$19,387	$11,246	$15,568	$14,296	$33,360	$13,621	$5,031	$12,519	$229,620
Sheepshead										$50		$50
Shellfish	$1,027,502	$2,955,217	$2,078,790	$1,293,713	$302,402	$70,872	$68,649				$455,459	$8,252,604
Shrimp, brown						$1,095	$18,558					$19,654
Shrimp, marine, other	$1,352,270	$1,343,639	$554,218	$575,269	$571,701	$1,092,283	$917,437	$576,018	$380,712	$65,984	$168,653	$7,598,184
Silversides										$4		$4
Skates	$1,253,043	$1,119,667	$1,611,536	$2,058,800	$4,239,421	$1,422,682	$4,386,298	$1,496,587	$2,494,605	$1,829,753	$2,359,267	$24,271,659
Smelt, rainbow	$60	$2,724	$84	$84								$2,952
Snails (conchs)					$86,903	$358,700	$344,902	$302,393	$380,212	$381,402	$431,736	$2,286,248
Spot				$15					$15			$30
Squid, longfin	$562,922	$1,012,051	$463,675	$815,094	$649,976	$889,908	$877,499	$1,006,012	$1,292,914	$2,120,212	$1,610,534	$11,300,797
Squid, northern shortfin	$27	$36	$192	$348	$535	$117		$544	$558,293	$308,847	$6,004	$874,943
Squids	$10,024	$10,149	$2,707	$19,094	$19,680	$22,918	$109,119	$358,390	$37,903	$70,776	$7,450	$668,210
Sturgeons	$524	$645	$89	$308	$12	$500						$2,078
Sword-fish	$7,724,561	$5,213,806	$5,106,971	$4,369,054	$4,174,420	$4,621,991	$3,428,561	$2,397,245	$2,389,189	$2,705,730	$3,435,687	$45,567,215
Tautog	$123,843	$149,214	$113,930	$118,782	$30,285	$30,413	$28,562	$96,259	$147,724	$141,239	$166,163	$1,146,414
Tilefish	$14,543	$3,256	$7,017	$27,182	$9,367	$2,769	$529	$966	$13,042	$8,581	$286	$87,538
Toadfishes											$1	$1
Tuna, albacore	$39,178	$11,706	$13,717	$5,195	$19,036	$18,188	$11,777	$12,086	$4,108	$2,844	$6,937	$144,772
Tuna, bigeye	$152,275	$375,764	$298,085	$522,550	$345,593	$566,426	$557,283	$466,726	$275,677	$196,521	$402,347	$4,159,247
Tuna, bluefin	$17,695,590	$10,383,269	$9,067,201	$12,256,397	$11,576,322	$13,134,219	$13,016,964	$13,172,177	$8,777,311	$11,781,784	$15,986,813	$136,848,047
Tuna, little tunny		$9,375	$3,752	$6,189				$318	$957	$1,679	$238	$22,508
Tuna, skipjack	$39	$111,299	$78,400	$22		$324						$190,084
Tuna, yellowfin	$208,919	$432,208	$219,193	$43,823	$39,055	$96,955	$135,878	$117,014	$48,559	$43,366	$68,307	$1,453,277
Tunas	$15,156	$254	$991	$34	$3,973	$3,759	$8,966	$13,624	$14,283	$3,271	$6,762	$71,073
Wahoo		$53	$2,129			$99	$47		$153	$48		$2,529
Weakfish	$1,342	$1,036	$1,352	$524		$408	$69	$7	$293	$1,991	$398	$7,420

Table G1-6: Revenue from Commercial Landings in Massachusetts, 1990-2000 (cont.)

Species	Year											Total
	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	
Wolffish, Atlantic	$207,824	$245,031	$213,235	$226,921	$266,351	$277,000	$226,469	$189,208	$233,373	$165,885	$129,913	$2,381,210
Total	$306,288,166	$302,268,505	$291,782,863	$238,744,112	$206,482,688	$220,229,427	$232,152,132	$225,036,618	$206,089,767	$260,504,185	$288,266,950	$2,777,845,413

* Note: "All annual and monthly landing summaries will return only nonconfidential landing statistics. Federal statutes prohibit public disclosure of landings (or other information) that would allow identification of the data contributors and possibly put them at a competitive disadvantage. Most summarized landings are nonconfidential, but whenever confidential landings occur they have been combined with other landings and usually reported as "finfishes, unc" (unclassified) or "shellfishes, unc." Total landings by state include confidential data and will be accurate, but landings reported by individual species may, in some instances, be misleading due to data confidentiality (Personal communication, National Marine Fisheries Service, Fisheries Statistics and Economics Division, Silver Spring, MD, 2002)."

G1-3.3 Recreational Activities

a. Recreational fishing

Striped bass (*Morone saxatilis*), summer flounder (*Paralichthys detatus*), Atlantic cod, scup (*Stenotomus chrysops*), and bluefish had the greatest number of recreational landings in New England between 1990 and 1998. Information from the Marine Recreational Fisheries Statistics Survey (MRFSS) (NMFS, 2001b), a long-term monitoring program that provides estimates of effort, participation, and finfish catch by recreational fishermen, indicates that 644 marine fishing sites are located near the three main New England power plants, which are the Seabrook and Pilgrim facilities and the Brayton Point station in Massachusetts, located on Mount Hope Bay, an upper embayment of Narragansett Bay (Figure G1-2).

EPA used data from both the MRFSS intercept and telephone interviews to evaluate fishing activities in the vicinity of the Seabrook, Pilgrim, and Brayton Point facilities. MRFSS intercept interviews were conducted at a subset of all NMFS sites. Approximately 70 percent of all sites near each plant were included in the survey. A total of 17,397 intercept surveys were completed at the fishing sites located in the 50-mile radius from the three plants, along with 14,936 telephone surveys.

Table G1-7 presents the number of NMFS sites within 50 miles of each of the three facilities, MRFSS intercept sites, and the number of surveys included in this analysis.

Table G1-7: Intercept Interview Statistics for Sites within 50 Miles of the Three Major New England Power Plants

	Brayton Point	Pilgrim	Seabrook	Total[a]
NMF sites	410	415	213	644
Intercept sites	242	293	140	399
Number of intercept interviews	19,524	14,923	8,436	28,260
Number of telephone interviews	14,282	11,150	6,640	21,710

[a] The total number of sites is less than the sum from each power plant because some sites are within 50 miles of both the Pilgrim and Brayton Point plants.

Both the Brayton Point and Pilgrim power plants are near highly populated areas, Boston and Providence. Because the majority of recreational fishermen (83 percent) take single day trips and prefer to visit fishing sites closer to their hometown, both the number of fishing sites and the number of fishing trips to these sites are higher near Brayton Point and Pilgrim compared to the Seabrook plant.

MRFSS data indicate that roughly 30 percent of fishermen near the New England facilities target small game species, including striped bass, Atlantic mackerel, and blue fish. Roughly 9 percent of recreational fishermen specifically targeted striped bass and an additional 5 percent specifically targeted either bluefish or Atlantic mackerel. Nearly twice as many fishermen target small game than the next most popular species group, bottom fish (e.g., Atlantic cod and scup). Nine percent of recreational fishermen target flounders and other flatfish and three percent target Atlantic cod. Less than 1 percent specifically targets scup.

Between 35 and 40 percent of fishermen do not target any species. Over half of "no target" fishermen fish from the shore and tend to catch "whatever bites." They often catch small game species because a number of these species have aggressive behavior and are easy to catch from shore. The percentage of fishermen targeting big game species (e.g., shark, swordfish, tarpon) ranges from 10 percent at sites near the Brayton Point plant to less than 5 percent at sites affected by either Seabrook or Pilgrim.

Figure G1-2: NMFS Recreational Fishing Sites and Power Plants
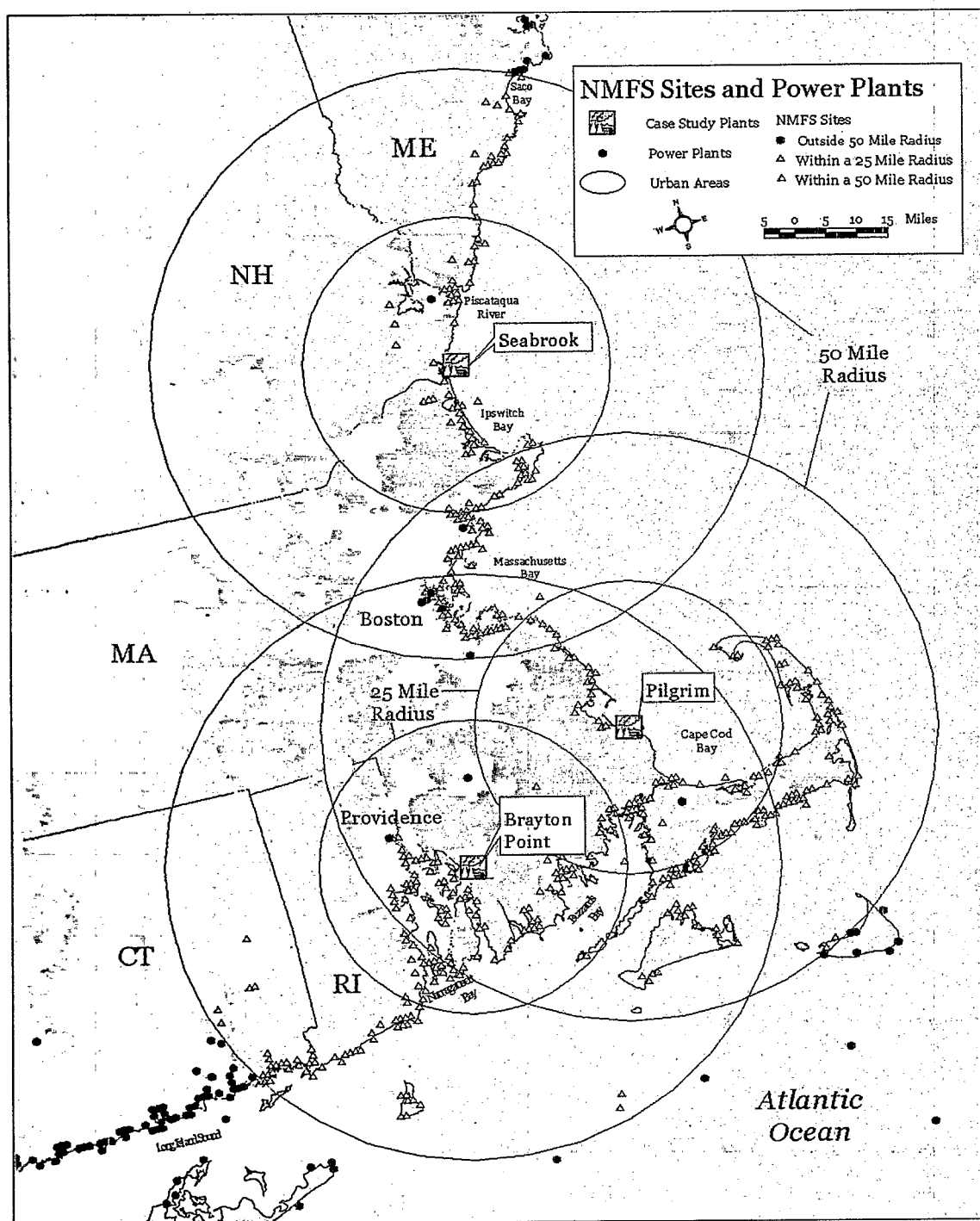
b. Tourism and other recreational activity

The Hampton/Seabrook estuary is the most popular recreational softshell clam harvesting area in New Hampshire (New Hampshire Estuaries Project, 2002). The sandy beaches of the area are a popular tourist destination, and are heavily used. Because of overuse and human development, the dunes in the Hampton/Seabrook estuary have been drastically reduced, and restoration of sand and dunegrass has recently begun (New Hampshire Estuaries Project, 2002).

Nonfishing related boating activity in the area around Seabrook is primarily recreational, and includes sailing, water skiing, wind surfing, rowing, kayaking, and canoeing. Just over 90% of the boats registered for "fresh and tidal water" were in the "private/rental" class (New Hampshire Estuaries Project, 2002).

Many historical sites attract tourists to Massachusetts bays from around the world, including the area near the Pilgrim facility. Plymouth County is one of the leading counties in Massachusetts in terms of tourism revenue.
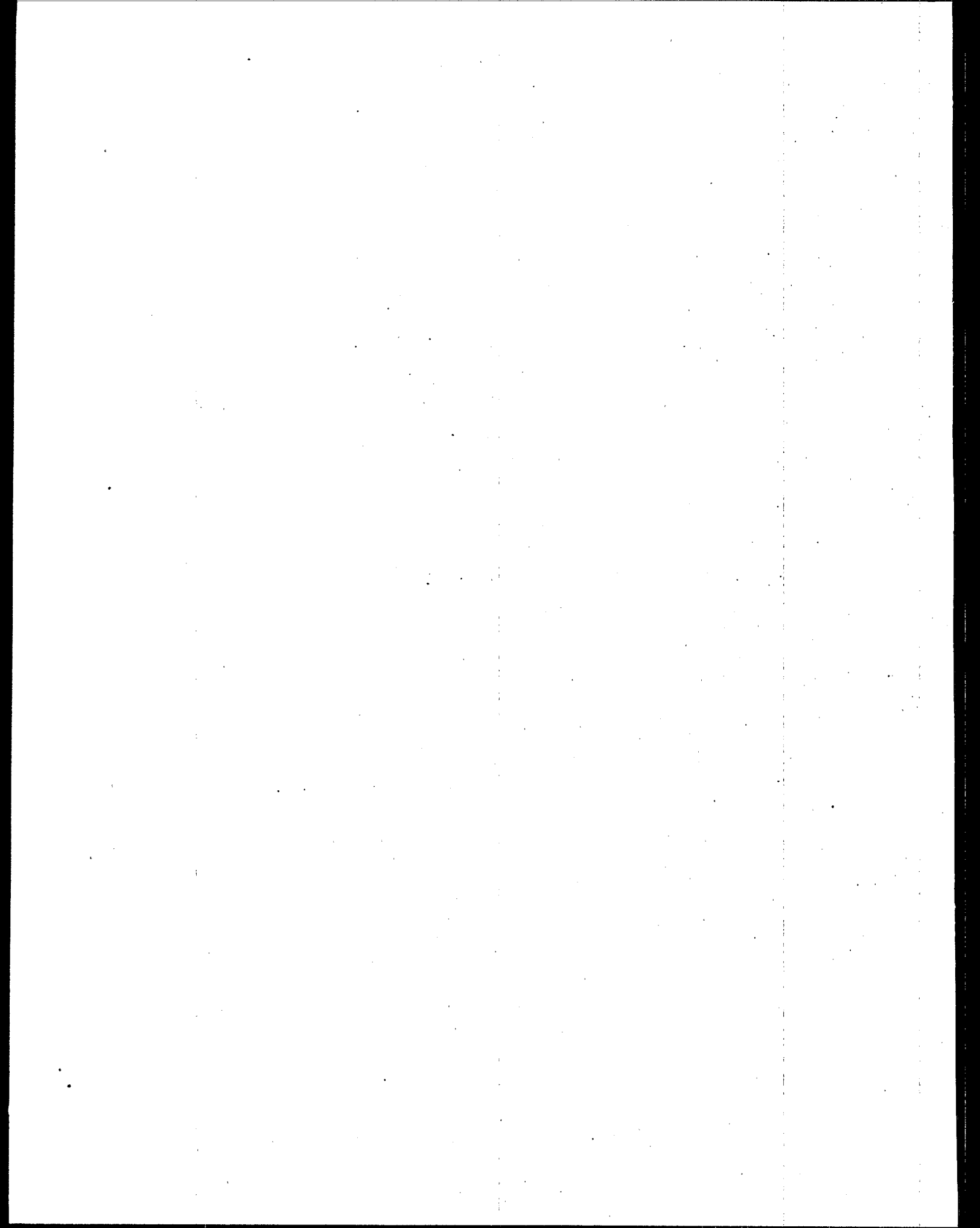
Chapter G2:

Technical and Economic Descriptions of the Seabrook and Pilgrim Facilities

G2-1   OPERATIONAL PROFILE

a. Seabrook

The Seabrook power plant operates one 1,240 MW
nuclear unit. The unit began operation in July of 1990 and
uses cooling water withdrawn from the Atlantic ocean.
Seabrook's total net generation in 1999 was 8.7 million
MWh; its capacity utilization was 79.9 percent. Table G2-1
presents generator details for the Seabrook power plant.

Table G2-1: Generator Detail of the Seabrook Plant (1999)

Generator ID	Capacity (MW)	Prime Mover[a]	Energy Source[b]	In-Service Date	Operating Status	Net Generation (MWh)	Capacity Utilization[c]	ID of Associated CWIS
PP01	1,240	NP	UR	Jul. 1990	Operating	8,681,836	79.9%	CW
Total	**1,240**					**8,681,836**	**79.9%**	

[a] Prime mover categories: NP = nuclear.
[b] Energy source categories: UR = uranium.
[c] Capacity utilization was calculated by dividing the unit's actual net generation by the potential generation if the unit ran at full capacity
all the time (i.e., capacity * 24 hours * 365 days).
Source: U.S. Department of Energy, 2001a, 2001b.

Figure G2-1 below presents Seabrook's electricity generation history between 1990 and 2000.

Figure G2-1: Seabrook Net Electricity Generation 1990 - 2000 (in MWh)
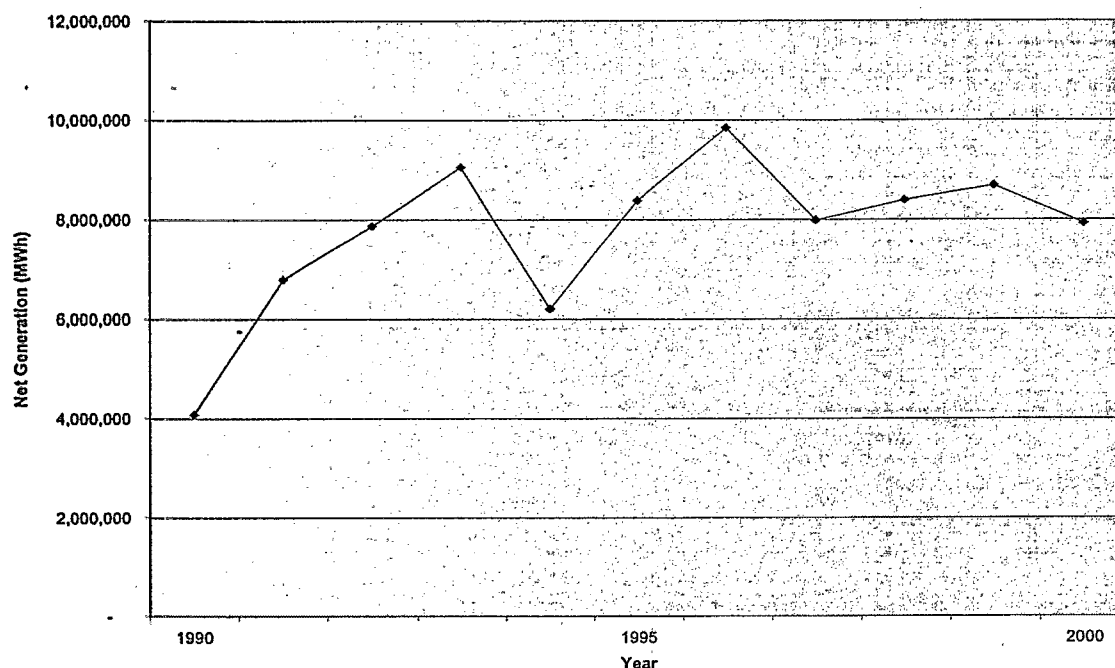
Source: U.S. Department of Energy, 2001d.

b. Pilgrim

The Pilgrim power plant operates one 670 MW nuclear unit. The unit began operation in December of 1972 and uses cooling water withdrawn from Cape Cod Bay. Pilgrim's total net generation in 1999 was 4.5 million MWh. Its capacity utilization was 76.2 percent. The plant was sold to Entergy Nuclear, a nonutility, in July of 1999. Table G2-2 presents generator details for the Pilgrim power plant.

Table G2-2: Pilgrim Generator Characteristics (1999)								
Generator ID	Capacity (MW)	Prime Mover[a]	Energy Source[b]	In-Service Date	Operating Status[c]	Net Generation (MWh)	Capacity Utilization[d]	ID of Associated CWIS
1	670	NB	UR	Dec. 1972	SD - Jul. 1999	4,473,327	76.2%	27
Total	**670**					**4,473,327**	**76.2%**	

[a] Prime mover categories: NB = nuclear.
[b] Energy source categories: UR = uranium.
[c] Operating Status: SD = sold to nonutility
[d] Capacity utilization was calculated by dividing the unit's actual net generation by the potential generation if the unit ran at full capacity all the time (i.e., capacity * 24 hours * 365 days).
Source: U.S. Department of Energy, 2001a, 2001b.

Figure G2-2 below presents Pilgrim's electricity generation history between 1972 and 2000.

Figure G2-2: Pilgrim Net Electricity Generation 1972 - 2000 (in MWh)
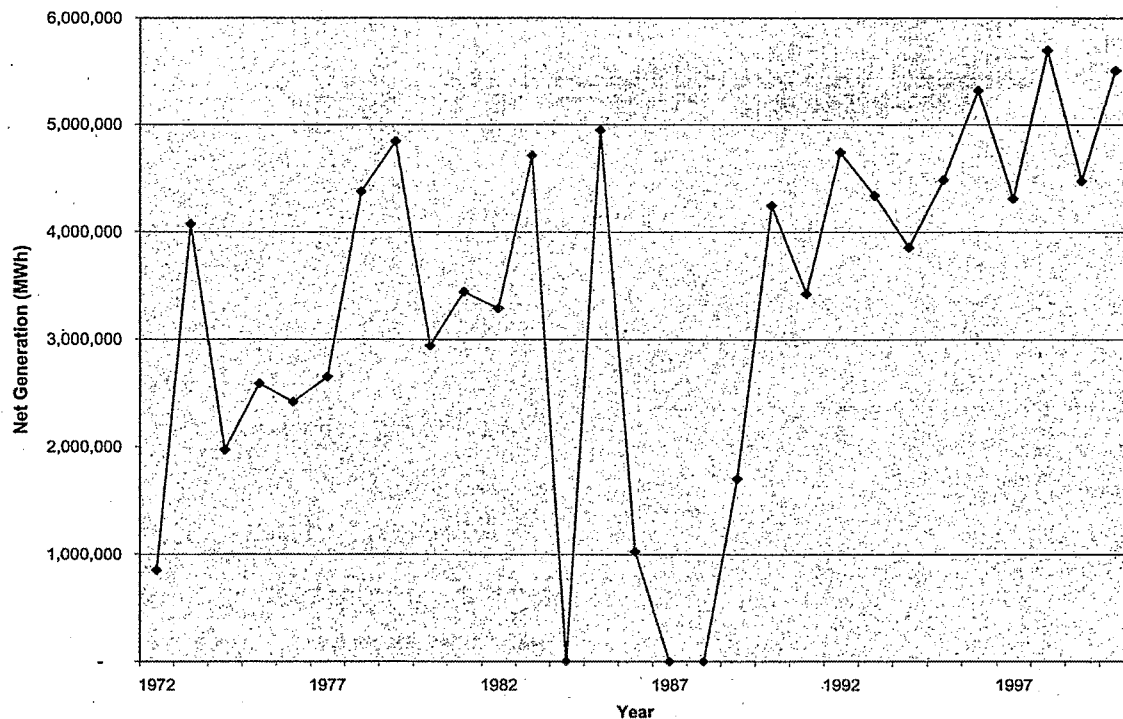
Source: U.S. Department of Energy, 2001d.

G2-2 CWIS CONFIGURATION AND WATER WITHDRAWAL

a. Seabrook

The Seabrook Power Station has an intake structure that is located 7,000 feet offshore in the Atlantic Ocean. The intake structure includes a velocity cap and screens. The facility's 1993 NPDES permit limited the approach velocity to 1.0 feet/second. Intake water flows through a 19-foot diameter tunnel to the plant. The design intake capacity is 918 cfs (593 mgd), which is also the approximate daily intake flow.

b. Pilgrim

The Pilgrim Power Station has two shoreline intakes that draw water from Cape Cod Bay. Intake water is obtained from an embayment, which is separated by two large breakwaters from the open waters of the Bay. The intake structures consist of a skimmer wall, vertical bar racks, and vertical conventional traveling screens. The average approach velocity is 1 foot per second. The screens are periodically rotated based on pressure differential as well as continuously at temperatures less than 30 degrees F to prevent freezing. The intake structure has a dual spray wash system with an initial low pressure wash to remove light fouling and organisms and a high pressure spray to remove debris. The design intake capacity is 693 cfs (448 mgd), which is also the approximate daily intake flow.
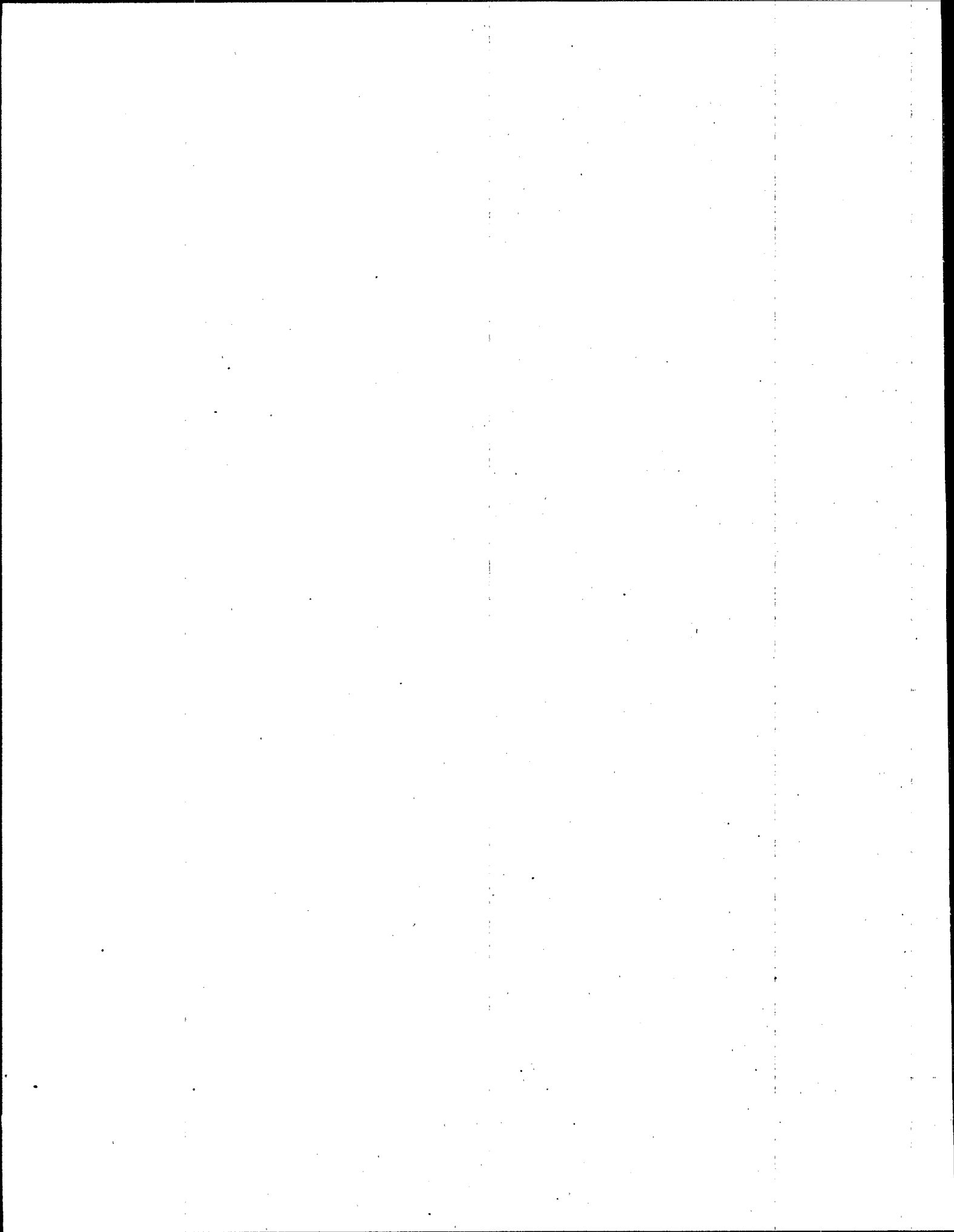
Chapter G3:

Evaluation of I&E Data

EPA evaluated I&E impacts to aquatic organisms resulting from the CWIS of the Seabrook and Pilgrim facilities using the assessment methods outlined in Chapter A2 of Part A of this document. Section G3-1 of this chapter lists fish species that are impinged and entrained at Seabrook and Pilgrim and Section G3-2 presents life histories of the most abundant species in the facilities' I&E collections. Section G3-3 outlines Seabrook's I&E collection methods and Section G3-4 presents results of EPA's analysis of annual impingement and entrainment at Seabrook. Section G3-5 outlines Pilgrim's I&E collection methods and Section G3-6 presents annual impingement and entrainment results for Pilgrim. Section G3-7 summarizes and compares I&E results for the two facilities and Section G3-8 discusses some potential biases and uncertainties in I&E results.

G3-1 AQUATIC SPECIES VULNERABLE TO I&E AT THE SEABROOK AND PILGRIM FACILITIES

EPA evaluated aquatic species impinged and entrained by the Seabrook and Pilgrim facilities, including commercial, recreational, and forage species, based on information provided in facility I&E monitoring reports. Approximately 84 different species of fish have been identified in I&E collections at Seabrook since monitoring began in 1990, and at least 58 (69%) of these are valued commercially or recreationally (Normandeau Associates, 1991, 1993, 1994a, 1994b, 1995, 1996a, 1996b, 1997, 1999). At the Pilgrim facility, approximately 68 species have been identified in I&E collections since 1974, and 26 (38%) of these have commercial or recreational value (Boston Edison Company, 1991-1994, 1995a, 1995b, 1996-1999, Stone & Webster Engineering Corporation, 1977). Table G3-1 lists species identified in Seabrook and Pilgrim I&E collections. Species with impingement or entrainment losses above one percent of total impingement or entrainment losses respectively were evaluated. Species with similar life histories were evaluated together.

Table G3-1: Aquatic Species Vulnerable to I&E at the Seabrook and Pilgrim Facilities						
Common Name	**Scientific Name**	**Seabrook**	**Pilgrim**	**Commercial**	**Recreational**	**Forage**
Alewife	*Alosa pseudoharengus*		✓		X	
Alligatorfish	*Aspidophoroides monopterygius*	✓				X
American eel	*Anguilla rostrata*	✓	✓	X	X	
American lobster	*Homarus americanus*	✓		X	X	
American plaice	*Hippoglossoides platessoides*	✓	✓	X		
American sand lance	*Ammodytes americanus*	✓	✓			X
American shad	*Alosa sapidissima*	✓		X	X	
Atlantic cod	*Gadus morhua*	✓		X	X	
Atlantic herring	*Clupea harengus*	✓	✓	X		
Atlantic mackerel	*Scomber scombrus*	✓	✓	X	X	
Atlantic menhaden	*Brevoortia tyrannus*	✓	✓	X	X	
Atlantic moonfish	*Selene setapinnis*	✓	✓			X

Table G3-1: Aquatic Species Vulnerable to I&E at the Seabrook and Pilgrim Facilities (cont.)

Common Name	Scientific Name	Seabrook	Pilgrim	Commercial	Recreational	Forage
Atlantic seasnail	*Liparis atlanticus*	✓				X
Atlantic silverside	*Menidia menidia*	✓	✓			X
Atlantic tomcod	*Microgadus tomcod*	✓	✓		X	
Atlantic torpedo	*Torpedo nobiliana*					X
Bay anchovy	*Anchoa mitchilli*		✓			X
Black ruff	*Centrolophus niger*	✓				X
Black sea bass	*Centropristis striata*	✓	✓	X	X	
Blackspotted stickleback	*Gasterosteus wheatlandi*	✓				X
Blue mussel	*Mytilus edulis*	✓	✓	X		
Blueback herring	*Alosa aestivalis*	✓	✓		X	
Bluefish	*Pomatomus saltator*	✓	✓	X	X	
Butterfish	*Peprilus triacanthus*	✓	✓	X	X	
Clearnose skate	*Raja eglanteria*	✓				X
Conger eel	*Conger oceanicus*	✓		X		
Cunner	*Tautogolabrus adspersus*		✓	X	X	
Flying gurnard	*Dactylopterus volitans*	✓	✓			X
Fourbeard rockling	*Enchelyopus cimbrius*	✓	✓			X
Fourspine stickleback	*Apeltes quadracus*	✓				X
Fourspot flounder	*Paralichthys oblongus*	✓	✓	X		
Goosefish	*Lophius americanus*	✓		X		
Grubby	*Myoxocephalus aenaeus*	✓	✓			X
Gulf snailfish	*Liparis coheni*	✓				X
Haddock	*Melanogrammus aeglefinus*	✓		X	X	
Hake species	Lotidae	✓	✓	X	X	
Herring species	Clupeidae			X	X	
Hogchoker	*Trinectes maculatus*	✓	✓			X
Killifish species	Fundulidae	✓			X	
Lefteye flounder	Bothidae	✓		X	X	
Little skate	*Leucoraja erinacea*	✓	✓	X		
Longhorn sculpin	*Myoxocephalus octodecemspinosus*	✓	✓	X		
Lumpfish	*Cyclopterus lumpus*	✓	✓			X
Moustache sculpin	*Triglops murrayi*	✓				X
Mummichog	*Fundulus heteroclitus heteroclitus*	✓	✓			X
Northern kingfish	*Menticirrhus saxatilis*	✓	✓		X	
Northern pipefish	*Syngnathus fuscus*	✓	✓			X
Northern puffer	*Sphoeroides maculatus*	✓	✓			X
Northern searobin	*Prionotus carolinus*	✓	✓			X
Ocean pout	*Zoarces americanus*			X		
Orange filefish	*Aluterus schoepfii*	✓	✓			X
Oyster toadfish	*Opsanus tau*					X
Pearlside	*Maurolicus muelleri*	✓	✓			X
Planehead filefish	*Stephanolepis hispidus*	✓	✓			X
Pollock	*Pollachius pollachius*	✓	✓	X	X	
Radiated shanny	*Ulvaria subbifurcata*	✓	✓			X
Rainbow smelt	*Osmerus mordax mordax*	✓	✓	X	X	
Red hake	*Urophycis chuss*	✓	✓	X		
Redfish (Red drum)	*Sciaenops ocellatus*	✓		X		
Righteye flounders	Pleuronectidae	✓		X	X	
Rock gunnel	*Pholis gunnellus*	✓	✓			X
Rough scad	*Trachurus lathami*					X
Round scad	*Decapterus punctatus*		✓			X
Sand lance species	*Ammodyte spp.*	✓	✓			X
Sand tiger	*Carcharias taurus*	✓				X

Table G3-1: Aquatic Species Vulnerable to I&E at the Seabrook and Pilgrim Facilities (cont.)

Common Name	Scientific Name	Seabrook	Pilgrim	Commercial	Recreational	Forage
Sculpin species	Cottidae	✓	✓	X		
Scup	*Stenotomus chrysops*	✓	✓	X	X	
Sea lamprey	*Petromyzon marinus*	✓				X
Sea raven	*Hemitripterus americanus*	✓				X
Searobin species	Triglidae	✓	✓		X	
Shorthorn sculpin	*Myoxocephalus scorpius*	✓	✓			X
Silver hake/Atlantic whiting	*Merluccius bilinearis*		✓	X	X	
Silver-rag	*Ariomma bondi*	✓	✓			X
Skate species	Rajidae			X		
Smallmouth flounder	*Etropus microstomus*		✓			X
Smooth dogfish	*Mustelus canis*	✓	✓			X
Smooth flounder	*Pleuronectes putnami*	✓				X
Snailfish species	Cyclopteridae	✓	✓			X
Spiny dogfish	*Squalus acanthias*		✓	X		
Spot	*Leiostomus xanthurus*		✓			X
Spotted hake	*Urophycis regia*	✓	✓			X
Striped anchovy	*Anchoa hepsetus*	✓				X
Striped bass	*Morone saxatilis*	✓	✓	X	X	
Striped cusk-eel	*Ophidion marginatum*		✓			X
Striped killifish	*Fundulus majalis*		✓			X
Striped searobin	*Prionotus evolans*	✓	✓			X
Summer flounder	*Paralichthys dentatus*	✓	✓	X	X	
Tautog	*Tautoga onitis*	✓	✓	X	X	
Threespine stickleback	*Gasterosteus aculeatus aculeatus*	✓	✓			X
White hake	*Urophycis tenuis*	✓	✓	X		
White perch	*Morone americana*	✓	✓	X	X	
Windowpane	*Scophthalmus aquosus*	✓	✓	X	X	
Winter flounder	*Pleuronectes americanus*	✓	✓	X	X	
Witch flounder	*Glyptocephalus cynoglossus*	✓		X		
Wolf-fish	*Anarhichas lupus*	✓			X	
Wrymouth	*Cryptacanthodes maculatus*	✓				X
Yellowtail flounder	*Limanda ferruginea*		✓	X	X	

Sources: Saila et al., 1997; Stone & Webster Engineering Corporation, 1977; Normandeau Associates 1991, 1993-1995, 1996a, 1996b, 1997; Boston Edison Company, 1991-1994, 1995a, 1995b, 1996-1999.

G3-2 LIFE HISTORIES OF MOST ABUNDANT SPECIES IN SEABROOK AND PILGRIM I&E COLLECTIONS

Atlantic cod (*Gadus morhua*)

Atlantic cod is a member of the Gadidae family, which includes cods and haddocks. The species is found from Greenland south to Cape Hatteras, North Carolina (Fahay et al., 1999). Atlantic cod is an extremely important commercial and recreational fish in the United States and Canada. The northern cod stock declined by almost two orders of magnitude between 1962 and 1992. The collapse of the fishery was due to excessive pressure from fishing (Hutchings, 1996). The 1987 year class was the largest in the period from 1982 to 1998; however, recruitment remains poor and year classes through the 1990s were weak (NOAA, 2001c). Currently the United States and Canadian Atlantic cod fisheries are managed through techniques such as closures, minimum size limits, days-at-sea restrictions, and quotas.

In U.S. waters, cod are evaluated and managed as two stocks, (1) the Gulf of Maine, and (2) Georges Bank and south (NEFSC, 2000b). Commercial and recreational fishing occurs throughout the year, but most recreational fishing occurs in late summer in the lower Gulf of Maine. Both commercial and recreational fishing are managed under the New England

Fishery Management Council's Northeast Multispecies Management Plan. The goal of the plan is to reduce fishing mortality to levels which will allow stocks to rebuild.

Spawning begins in northern areas as early as February and ends in southern areas as late as December (Scott and Scott, 1988). Cod spawn repeatedly for up to 50 days once a year (Kjesbu, 1989). Annual fecundity increases with age and size (May, 1967), with large females producing between 3 to 9 million eggs (Fahay et al., 1999). Spawning occurs at various depths, from less than 110 m (360 ft) to more than 182 m (597 ft), depending on water temperature (Scott and Scott, 1988). Eggs are distributed throughout the water column, although their buoyancy tends to concentrate them in a cold intermediate layer if the water is stratified (Ouellet, 1997). Egg development in cooler waters (0 °C or 32 °F) usually extends for 40 days (Scott and Scott, 1988; Ouellet, 1997).

The pelagic larvae move to the bottom during the day and rise at night (Lough and Potter, 1993; Gotceitas et al., 1997). Age 0 and age 1 cod are both found in nearshore environments, preferably over sandy substrates (Fraser et al., 1996), and young cod often seek cover in eelgrass (*Zostera marina*) (Gotceitas et al., 1997). Juveniles 40 mm (0.16 in.) or larger are demersal by day, but will frequently rise up to 5 m (16 ft) off the bottom at night (Lough and Potter, 1993).

Atlantic cod eat a variety of foods throughout their lifetime (Scott and Scott, 1988). Fry eat copepods, amphipods, larvae, and small crustaceans; juveniles eat larger crustaceans; and adults over 50 cm (19 in.) eat fish, including smaller cod, as well as invertebrates. Age 0 cod primarily feed during the day, while age 1 cod generally feed at night (Grant and Brown, 1998).

Adult Atlantic cod live in diverse habitats ranging from inshore waters to the outer continental shelf, and from depths of 457 m (1,500 ft) to surface waters. They generally prefer cooler water temperatures ranging from -0.5 to 10 °C (31 to 50 °F; Scott and Scott, 1988). Off the New England coast, Atlantic cod migrate seasonally, moving into coastal waters in the fall and returning to deeper waters during spring (Fahay et al., 1999). Adults reach sexual maturity at ages 2 to 4 (NOAA, 2001c). Cod can reach a total length of 200 cm (78 in.), a maximum weight of 96 kg (212 lb), and a maximum age of 25 (Froese and Pauly, 2001).
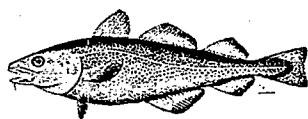
ATLANTIC COD
(Gadus morhua)

Family: Gadidae (cods and haddocks).

Common names: Atlantic cod.

Similar species: Greenland cod (*G. ogac*), Pacific cod (*G. macrocephalus*).

Geographic range: Can be found from Greenland south to Cape Hatteras, North Carolina.[a]

Habitat: Diverse habitats ranging from inshore waters to the outer continental shelf, and from depths of 457 m (1,500 ft) to surface waters.[b]

Lifespan: Maximum reported age is 25 years.[c]

Fecundity: Large females may produce between 3 to 9 million eggs.[a]

Food source: Larvae and juveniles consume copepods, amphipods, larvae, and crustaceans. Adults feed on fish, including smaller cod, as well as invertebrates.[b] Age 0 cod feed during the day, Age 1 cod feed primarily at night.[d]

Prey for: Larger cod, squid, pollock, and seals.[c]

Life stage information:

Eggs: pelagic
▶ Distributed throughout the water column.[e]

Larvae: pelagic
▶ Move to the bottom during the day and rise at night.[f]
▶ Found in nearshore environments, preferably over sandy substrates or in eelgrass.[g,h]

Juveniles: demersal
▶ Larger juveniles are mainly demersal, but will rise up to 5 m (16 ft) off the bottom at night.[f]

Adults:
▶ Adult Atlantic cod in the Gulf of Maine migrate northward in fall, traveling up to 500 km (310 miles) to overwinter off of eastern Canada.[i]
▶ Move into coastal waters in the fall, and return to deeper waters during spring.[a]

[a] Fahay et al., 1999.
[b] Scott and Scott, 1988.
[c] Froese and Pauly, 2001.
[d] Grant and Brown, 1998.
[e] Ouellet, 1997.
[f] Lough and Potter, 1993
[g] Fraser et al., 1996.
[h] Gotceitas et al., 1997.
[i] Campana et al., 1999.
Fish graphic from NOAA, 2002e.

Atlantic herring (*Clupea harengus*)

Atlantic herring is a member of the Clupeidae family, which includes herring, sardines, and shads. It ranges from southwestern Greenland and Labrador to South Carolina (Scott and Scott, 1988). Herring fisheries developed in the late 1800's, concurrent with the development of canning technology. Herring were also used as bait for the lobster industry, which developed at about the same time. Annual landings were as high as 68 million kg (150 million lb) in the late 1800's (Atlantic States Marine Fisheries Commission, 2001a). Particularly aggressive foreign fisheries developed in the 1960's on Georges Bank, with landings peaking at 363 million kg (800 million lb) in 1968. This overfishing contributed to a crash of the Atlantic herring population. Current annual harvests are in the range of 36 to 45 million kg (80 to 100 million lb) (Atlantic States Marine Fisheries Commission, 2001a). Primary uses of Atlantic herring are as canned sardines, steaks, and bait for crab, lobster, and tuna fisheries (Atlantic States Marine Fisheries Commission, 2001a).

Atlantic herring along the northeastern Atlantic coast were previously managed as two stocks, the Gulf of Maine stock and the Georges Bank stock. However, herring from the two stocks are now considered together as a single coastal stock complex for current management purposes (NEFSC, 2000c). The offshore fishery collapsed in 1977, and subsequently the commercial fishery focused on the near shore waters of the Gulf of Maine. Stock biomass has increased substantially in recent years because of increased spawning and low fishing mortality. Recreational landings in recent years have been inconsequential.

Spawning occurs throughout the year, peaking in shallow waters in the spring and deeper waters in the fall (Scott and Scott, 1988). Spawning in waters of coastal Massachusetts takes place usually in October or November at depths ranging from 4 to 110 m (13 to 360 ft) (Kelly and Moring, 1986). Adults may travel long distances to return to spawning grounds, which consist of rock, gravel, or sandy substrates (Kelly and Morning, 1986). Fecundity increases with age and size, with females producing between 23,000 and 261,000 eggs (Messieh, 1976). Atlantic herring eggs are demersal, stick to the bottom in clumps or layers, and often cover the substrate (Atlantic States Marine Fisheries Commission, 2001a). Eggs are generally 1.0 to 1.4 mm (0.04 to 0.06 in.) in diameter and hatch after 10 to 30 days, depending on temperature. Larvae are 4 to 10 mm (less than 0.4 in.) in total length (Able and Fahay, 1998).

Larvae disperse to estuaries after hatching, and grow to approximately 30 mm (1.2 in.) long before transforming into juveniles (Able and Fahay, 1998). Transformation occurs after about 152 days at water temperatures of 7 to 12 °C (44 to 54 °F) (Doyle, 1977), but can last as long as 240 days for late-spawned (December) herring (Reid et al., 1999). Larvae hatched earlier in the season tend to grow faster than those hatched later (Jones, 1985). These juveniles, called "brit herring," move in large inshore schools. Larger juveniles are referred to as "sardines" and are harvested commercially (Jury et al., 1994).

Adults are found in coastal and continental shelf waters at depths of up to 200 m (656 ft) and in water temperatures from 1 to 18 °C (34 to 64 °F; Atlantic States Marine Fisheries Commission, 2001a; Froese and Pauly, 2001). Feeding migrations may consist of hundreds of thousands of adults. Schools are composed of individuals of similar size classes, and tend to inhabit the upper water column. Most Atlantic herring migrate south in the fall from feeding grounds off Maine to southern New England (Kelly and Moring, 1986).

Food sources are primarily small planktonic copepods in the first year, and copepods thereafter. Atlantic herring switch to filter feeding if the density and size of food are appropriate (Froese and Pauly, 2001). Adult herring will also eat fish eggs, pteropods (small molluscs), and the larvae of mollusks and fish (Scott and Scott, 1988).

Growth rates of Atlantic herring are highly variable by stock, and herring typically reach maturity between the ages of 3 and 5 (Scott and Scott, 1988). Environmental factors such as temperature, food availability, and population size generally control growth. Atlantic herring reach 250 mm (10 in.) by the fourth year and may eventually reach 380 mm (15 in.) and 0.68 kg (1.5 lb) (Atlantic States Marine Fisheries Commission, 2001a). A Gulf of St. Lawrence study reported Atlantic herring of 12 years (Scott and Scott, 1988).

ATLANTIC HERRING
(Clupea harengus)

Family: Clupeidae (herrings).[a]

Common names: sea herring, sardine, herring.[b]

Similar species: Pacific herring (*C. pallasii*), alewives (*Alosa pseudoharengus*).[a]

Geographic range: Can be found from southwestern Greenland and Labrador to South Carolina.[a]

Habitat: Coastal and continental shelf waters at depths of up to 200 m (656 ft).[a]

Lifespan: Up to 12 years.[a]

Fecundity: Females produce between 23,000 and 261,000 eggs.[c]

Food source: Young of year primarily feed on small planktonic copepods; adults consume larger copepods, fish eggs, pteropods (small molluscs), and the larvae of mollusks and fish.[a]

Prey for: Almost all pelagic predators as well as many seabirds, marine mammals, and bottom dwellers (eggs only).[a]

Life stage information:

Eggs: demersal
►   Stick to the bottom in clumps or layers, and often cover the substrate.[b]

Larvae: pelagic
►   Larvae disperse to estuaries after hatching.[d]

Juveniles: pelagic
►   Harvested commercially as "sardines."[e]

Adults:
►   Form schools of hundreds of thousands of individuals of the same size class.[f]
►   Most migrate south in the fall from feeding grounds off Maine to southern New England.[f]

[a] Scott and Scott, 1988.
[b] Atlantic States Marine Fisheries Commission, 2001a.
[c] Messieh, 1976.
[d] Able and Fahay, 1998.
[e] Jury et al., 1994.
[f] Kelly and Moring, 1986.
Fish graphic from Government of Newfoundland and Labrador, 2002.

Atlantic mackerel (*Scomber scrombrus*)

Atlantic mackerel is a member of the Scombridae family, which includes mackerels, tunas, and bonitos. Atlantic mackerel range from Labrador to Cape Lookout, North Carolina. The species tends to school in large groups in shelf areas with water temperatures of 9 to 12 °C (48 to 54 °F; Scott and Scott, 1988). Atlantic mackerel is fished both commercially and for sport. Fish caught in the United States and Canada peaked in 1973 at 400 million kg (400,000 metric tons) per year and declined to a low of 30 million kg (30,000 metric tons) in the late 1970's. Weak year classes occurred from 1975 through 1980 but stocks are currently very high (NEFSC, 2000a). Stock increases have resulted from low harvest rates combined with improved recruitment.

Winters are spent in deeper waters, but mackerel return to shore in springtime to spawn. There are two major spawning areas for Atlantic mackerel: between Cape Cod and Cape Hatteras, and in the Gulf of St. Lawrence (Scott and Scott, 1988). In the Gulf of St Lawrence, Atlantic mackerel spawn from June to mid-August, whereas in the northern regions of the Mid-Atlantic Bight they spawn from April to June (Ware and Lambert, 1985). In summer and fall, fish from the Mid-Atlantic Bight move into coastal areas along the Gulf of Maine, while the northern contingent remains in Canadian waters (Ware and Lambert, 1985).

Females are serial spawners, releasing five to seven successive batches of eggs each year (Morse, 1980b). Fecundity values for females in U.S. waters of the northwestern Atlantic range from approximately 156,000 to 1,640,000 eggs for females between 310 and 446 mm (12 to 19 in.) fork length (Griswold and Silverman, 1992). Eggs are pelagic and are released near the surface, where they concentrate in the upper 10 m (33 ft) of water (Scott and Scott, 1988). At hatching, larvae are about 3 mm (0.1 in.) long (Ware and Lambert, 1985). Larvae grow rapidly, reaching an average size of 200 mm (8 in.) by late fall (Scott and Scott, 1988).

Atlantic mackerel feed by both filter feeding and prey selection. Food sources include zooplankton, shrimp, crab larvae, small squid, fish eggs, and young fish such as capelin and herring. After spawning, adults generally migrate in schools to offshore feeding areas before returning to their overwintering sites (Scott and Scott, 1988).

Once juveniles join the offshore adults, they remain in schools. Adults are obligate swimmers owing to the absence of a swim bladder (Scott and Scott, 1988). Atlantic mackerel mature at about 2 years or 26 cm (10 in.) (NMFS, 1999b). They may live up to 17 years and attain length of up to 50 cm (20 in.) (Froese and Pauly, 2001).

ATLANTIC MACKEREL *(Scomber scombrus)*	**Food source:** Zooplankton, shrimp, crab larvae, small squid, fish eggs, and young capelin and herring.[a] **Prey for:** Porbeagle sharks, dogfish, Atlantic cod, bluefin tuna, swordfish, porpoises, and harbor seals.[a] **Life stage information:**
Family: Scombridae (mackerels, tunas, bonitos).[a] **Common names:** Mackerel, tinker (half-grown mackerel). **Similar species:** **Geographic range:** Can be found from Labrador, Canada to Cape Lookout, North Carolina.[a] **Habitat:** Open marine waters, mainly within the continental shelf.[b] **Lifespan:** Maximum reported age is 17 years.[c] **Fecundity:** Females produce approximately 156,000 to 1,640,000 eggs.[d]	*Eggs: pelagic* ▸ Eggs are released near the surface.[a] *Larvae: pelagic* ▸ Grow rapidly, reaching an average size of 200 mm (8 in.) by late fall.[a] *Juveniles:* ▸ Join the offshore adults and remain in schools.[b] *Adults:* ▸ School in large groups in shelf areas.[b] ▸ Are obligate swimmers owing to the absence of a swim bladder.[a]
[a] Scott and Scott, 1988. [b] Studholme et al., 1999. [c] Froese and Pauly, 2001. [d] Griswold and Silverman, 1992. Fish graphic from NOAA, 2001c.	

Atlantic menhaden (*Brevoortia tyrannus*)

The Atlantic menhaden is a member of the Clupeidae (herring) family, and is a euryhaline species, occupying coastal and estuarine habitats. It is found along the Atlantic coast of North America, from Maine to northern Florida (Hall, 1995). Adults congregate in large schools in coastal areas; these schools are especially abundant in and adjacent to major estuaries and bays. They consume plankton, primarily diatoms and dinoflagellates, which they filter from the water through elaborate gill rakers. In turn, menhaden are consumed by almost all piscivorous, recreationally important fish, as well as dolphins and birds (Hall, 1995).

The menhaden fishery is one of the most important and productive fisheries on the Atlantic coast, representing a multimillion-dollar enterprise worldwide (Hall, 1995). Menhaden are considered an "industrial fish" and are used in products such as paints, cosmetics, margarine (in Europe and Canada) and feed, as well as bait for other fisheries. The fishery in New England peaked in the 1950's with 36 million kg (36,000 metric tons) landed. Landings in the 1960's declined to their lowest level of approximately 2,700 kg (2.7 metric tons) because of overfishing. Since then, landings have varied, ranging from approximately 200,000 kg (200 metric tons) in 1989 to 1 million kg (1,000 metric tons) in 1998 (personal communication, National Marine Fisheries Service, Fisheries Statistics and Economics Division, Silver Spring, MD, March 19, 2001).

Atlantic menhaden spawn year round at sea and in larger bays. In waters from Maine to Massachusetts, spawning takes place from May to October (Scott and Scott, 1988). The majority of spawning occurs over the inner continental shelf, with lesser activity in bays and estuaries (Able and Fahay, 1998).

Females mature between ages 2 and 3, and release buoyant, planktonic eggs during spawning (Hall, 1995). Atlantic menhaden annual egg production ranges from approximately 40,000 to 700,000 eggs (Hall, 1995). Eggs are spherical and are between 1.3 to 1.9 mm (0.05 to 0.07 in.) in diameter (Scott and Scott, 1988).

Larvae hatch after approximately 24 hours and remain in the plankton. Those larvae that hatch at sea enter estuarine waters 1 to 2 months later (Hall, 1995). Water temperatures below 3 °C (37 °F) kill the larvae, and therefore larvae that fail to reach estuaries before the fall are more likely to die than those arriving in early spring (Able and Fahay, 1998). Larvae are 30 mm (0.1 in.) and 70 mg (0.0001 lb) and juveniles are 38 mm (0.15 in.) and approximately 470 mg (0.001 lb; Lewis et al., 1972). The juvenile growth rate is estimated to be 1 mm (0.04 in.) per day (Able and Fahay, 1998).

During the fall and early winter, most menhaden migrate south to the North Carolina capes, where they remain until March and early April. Few larvae can tolerate waters below 3 °C (37 °F), or waters that rapidly cool to 4.5 °C (40 °F). Adults and juveniles can tolerate a wide range of salinities from less than 1‰ up to 33-37‰ (Hall, 1995). Menhaden spawn in early spring and winter off North Carolina and in spring and late fall in the mid-Atlantic region (Wang and Kernehan, 1979). However, primary spawning grounds for Atlantic menhaden are offshore near Cape Cod (Jury et al., 1994).

Adult fish are usually 30-35 cm (12-14 in.) long and weigh 0.9 kg (2 lb). The maximum age of a menhaden is approximately 7 to 8 years (Hall, 1995), although individuals of 8-10 years have been recorded (Scott and Scott, 1988).

ATLANTIC MENHADEN
(*Brevoortia tyrannus*)

Family: Clupeidae (herrings).[a]

Common names: Menhaden, moss bunker, fatback.[b]

Similar species: Gulf menhaden (*B. patronus*), yellowfin menhaden (*B. smithi*).

Geographic range: From Maine to northern Florida along the Atlantic coast.[c]

Habitat: Open-sea, marine waters. Travels in schools.[a]

Lifespan: Approximately 7 to 8 years.[c]

Fecundity: Females produce between 40,000 to 700,000 eggs.[c]

Food source: Phytoplankton, zooplankton, annelid worms, detritus.[a]

Prey for: Sharks, cod, pollock, hakes, bluefish, tuna, swordfish, seabirds, whales, porpoises.[a]

Life stage information:

Eggs: *pelagic*
- Spawning takes place along the inner continental shelf, in open marine waters, with less activity in bay and estuaries.[d]
- Hatch after approximately 24 hours.[c]

Larvae: *pelagic*
- Hatch at sea, and enter estuarine waters 1 to 2 months later.[c]
- Remain in estuaries through the summer, emigrating to ocean waters as juveniles in September or October.[d]

Adults
- Congregate in large schools in coastal areas
- Spawn year round, primarily May to October from Main to Massachusetts.[a]

[a] Scott and Scott, 1988.
[b] Bigelow and Schroeder, 1953.
[c] Hall, 1995.
[d] Able and Fahay, 1998.
Fish graphic from U.S. EPA, 2002a.

Cunner (*Tautogolabrus adspersus*)

Cunner is a member of the Labridae family, which includes the tautog. Cunner is a dominant component of many temperate marine communities of the western Atlantic Ocean from Newfoundland to Chesapeake Bay (Bigelow and Schroeder, 1953). It is a territorial and sedentary species that occupies small, localized ranges within 10 km (6.2 miles) of shore. The species prefers complex habitats with natural or artificial structures such as bedrock outcrops, glacial boulders, pilings, shipwrecks, or breakwaters, and juveniles inhabit shallow waters (Lawton et al., 2000). Although large numbers of cunner were landed in the late 1800's and early 1900's, today they have little commercial or recreational value (Bigelow and Schroeder, 1953).

In Cape Cod Bay, cunner spawn close to shore from mid-March until mid-July (Lawton et al., 2000). In more northern areas the spawning season lasts from May to September. Spawning peaks in waters near Woods Hole, Massachusetts, during the first three weeks of June (Lawton et al., 2000). Males and females are able to spawn several times in a day, and more than once throughout the spawning season (Pottle and Green, 1979). Females produce approximately 5,000 to 600,000 eggs annually (Steimle and Shaheen, 1999). The number of eggs produced is related to fork length and fish weight; maximum egg production occurs between the ages of 7 and 9 years and is maintained until approximately 16 years of age (Steimle and Shaheen, 1999).

Cunner eggs are pelagic and range in size from 0.84 to 0.92 mm (0.033 to 0.036 in.) in diameter (Able and Fahay, 1998). Eggs hatch after several days in water temperatures of 12.8 to 18.3 °C (55 to 65 °F), and larvae are 2-3 mm (0.08 to 0.11 in.) long (Bigelow and Schroeder, 1953). The larval stage lasts 18-37 days (Lawton et al., 2000).

Cunner growth rates during the first year in waters near Nova Scotia range from 0.30 to 0.35 mm (0.01 in.) per day (Tupper and Boutilier, 1995). Larvae and juveniles collected in July in the Great Bay-Little Egg Harbor area, off the New Jersey shore, were 5.2-15.6 mm (0.2 to 0.6 in.) long (Able and Fahay, 1998). At age 1, cunner are about 4 to 8 cm (1.6 to 3.1 in.) long (Serchuk and Cole, 1974).

Adults do not migrate extensively, but they will travel short distances to escape extremes in water temperature (Bigelow and Schroeder, 1953). They move to protected areas in the fall and become inactive as water temperatures fall to 7-8 °C (45 to 46 °F). As temperatures decrease further, cunner become dormant (Olla et al., 1975). Some may overwinter in their summer habitat, but inshore areas that are susceptible to thermal currents are not suitable for the dormant period (Dew, 1976). When spring water temperatures reach 5 to 6 °C (41 to 43 °F), cunner move to seasonally transitory habitats such as mussel beds and seaweed (Olla et al., 1979). Cunner are active during the day and become inactive and seek cover at night (Olla et al., 1975). Cunner are omnivores that feed on mussels, small lobsters, and sea urchins in addition to plant material (State of Maine Division of Marine Resources, 2001b).

Dew (1976) found that cunner in the mid-Atlantic Bight mature at about age 1. Cunner sampled in Cape Cod Bay were up to 10 years old (Lawton et al., 2000), whereas data for other areas indicate a maximum age of 6 years (Froese and Pauly, 2001).
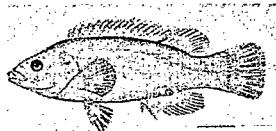
CUNNER(*Tautogolabrus adspersus*)

Family: Labridae (wrasses).

Common names: Perch, sea perch, blue perch, bergall, chogset, choggy.[a]

Similar species: Tautog (*Tautoga onitis*).

Geographic range: Prevalent from Newfoundland to Chesapeake Bay.[b]

Habitat: Natural or artificial structures within 10 km of shore.[c]

Lifespan: May live up to 10 years.[c]

Fecundity: Females produce approximately 5,000 to 600,000 eggs annually.[a]

Food source: Mussels, small lobsters, and sea urchins in addition to plant material.[d]

Prey for: Other shore fish such as sculpins, seabirds.[e]

Life stage information:

Eggs: pelagic
- Range in size from 0.84 to 0.92 mm (0.033 to 0.036 in.) in diameter.[f]

Larvae:
- 0.2-0.3 mm (.008 to 0.012 in.) in length.[b]

Juveniles:
- Can be found in high abundance in structurally complex habitats.[f]

Adults:
- Inactive as water temperatures fall, but they will travel short distances to escape extremes in temperature.[b]
- Become dormant in the winter.[g]

[a] Auster, 1989.
[b] Bigelow and Schroeder, 1953.
[c] Lawton et al., 2000.
[d] State of Maine Division of Marine Resources, 2001b.
[e] Scott and Scott, 1988.
[f] Able and Fahay, 1998.
[g] Olla et al., 1975.
Fish graphic from NOAA, 2002c.

Winter flounder (*Pleuronectes americanus*)

Winter flounder is a benthic flatfish of the family Pleuronectidae (righteye flounders), which is found in estuarine and continental shelf habitats. Its range extends from the southern edge of the Grand Banks south to Georgia (Buckley, 1989b). It is a bottom feeder, occupying sandy or muddy habitats and feeding on bottom-dwelling organisms such as shrimp, amphipods, crabs, urchins, and snails (Froese and Pauly, 2001).

Both commercial and recreational fisheries for winter flounder are important. U.S. commercial and recreational fisheries are managed under the New England Fishery Management Council's Multispecies Fishery Management Plan and the Atlantic States Marine Fisheries Commission's Fishery Management Plan for Inshore Stocks of Winter Flounder (NEFSC, 2000d). Three groups are recognized for management and assessment purposes: Gulf of Maine, Southern New England-Mid Atlantic, and Georges Bank. Management currently focuses on reducing fishing levels to reverse declining trends and rebuild stocks. The Gulf of Maine stock is currently considered overfished (NEFSC, 2000d). Although improvements in stock condition will depend on reduced harvest, the long-term potential catch (maximum sustainable yield) has not been determined.

The winter flounder is a nonmigratory species. Tagging studies indicate that winter flounder north of Cape Cod remain in local inshore waters, while populations south of Cape Cod may disperse up to 3 miles offshore on a seasonal basis (Buckley, 1989b). Water temperature seems to be the most important determining factor of seasonal distribution. Winter flounder near Newfoundland may remain in shallow waters during the summer as long as temperatures do not exceed 15 °C (59 °F), while off of the coast of Rhode Island, winter flounder move to deeper, cooler waters in the summer (Buckley, 1989b).

Spawning occurs between January and May in New England, with peaks in the Massachusetts area in February and March (Bigelow and Schroeder, 1953). Spawning habitat is generally in shallow water over a sandy or muddy bottom (Scott and Scott, 1988). Adult fish tend to leave the shallow water in autumn to spawn at the head of estuaries in late winter. The majority of spawning takes place in a salinity range of 31 to 33 ppt and a water temperature range of 0 to 3 °C (32 to 37 °F). Females will usually produce between 500,000 and 1.5 million eggs annually, which sink to the bottom in clusters. The eggs are about 0.74 to 0.85 mm (approximately 0.03 in.) in diameter, and hatch in approximately 15 to 18 days (Bigelow and Schroeder, 1953).

Larvae are about 3.0 to 3.5 mm (0.1 in.) total length when they hatch out. They develop and metamorphose over 2 to 3 months, with growth rates controlled by water temperature (Bigelow and Schroeder, 1953). Larval growth appears to be optimal with a slow increase from spawning temperatures of 2 °C (36 °F) to approximately 10 °C (50 °F; Buckley, 1982). Larvae depend on light and vision to feed during the day and do not feed at night (Buckley, 1989b). Juveniles tend to remain in shallow spawning waters, and stay on the ocean bottom (Scott and Scott, 1988).

Fifty percent of females reach maturity at age 2 or 3 in the waters of Georges Bank, while they may not mature until age 5 in more northern areas such as near Newfoundland. Females are generally 22.5 to 31.5 cm (8 to 12.4 in.) long at maturity (Howell et al., 1992).

Winter flounder supports important commercial and recreational fisheries in the area, as it is the thickest and meatiest of the common New England flatfish (Bigelow and Schroeder, 1953). Annual commercial landings declined from 17.083 million kg (17,083 metric tons) in 1981 to 3.223 million kg (3,223 metric tons) in 1994 (personal communication, National Marine Fisheries Society, Fish Statistics and Economics Division, Silver Spring, MD, January 16, 2002.). Winter flounder is ecologically important as a prey species for larger estuarine and coastal fish such as striped bass (*Morone saxatilis*) and bluefish (*Pomatomus saltatrix*) (Buckley, 1989b).

WINTER FLOUNDER
(*Pleuronectes americanus*)

Family: Pleuronectidae (righteye flounders)

Common names: Blackback flounder, lemon sole, black flounder.[a]

Similar species: American plaice (*Hippoglossoides platessoides*), European plaice (*P. platessus*).

Geographic range: From the southern edge of the Grand Banks south to Georgia.[b]

Habitat: Bottom dweller. Found in coastal marine waters.[c]

Lifespan: May live up to 15 years.

Fecundity: Females produce between 500,000 and 1.5 million eggs annually.[a]

Food source: Bottom-dwelling organisms such as shrimp, amphipods, crabs, urchins and snails.[a]

Prey for: Striped bass, bluefish.[b]

Life stage information:

Eggs: demersal
- Approximately 0.74 to 0.85 mm (0.03 in.) in diameter.[a]
- Hatch in approximately 15 to 18 days.[a]

Larvae: semi-pelagic
- Approximately 3.0 to 3.5 mm (0.1 in.) total length when they hatch out.[a]

Juveniles: demersal
- Once winter flounder enter the juvenile stage, they remain benthic, preferring sandy bottomed substrates.[d]

Adults:
- Females mature at ages 2 and 3.[e]
- Migrate seasonally to offshore waters in the summer, and inshore waters in the winter.[b]

[a] Bigelow and Schroeder, 1953.
[b] Buckley, 1989b.
[c] Scott and Scott, 1988.
[d] Grimes et al., 1989.
[e] Howell et al., 1992.
Fish graphic from State of Maine Department of Marine Resources, 2001d.

G3-3 SEABROOK'S METHODS FOR ESTIMATING IMPINGEMENT AND ENTRAINMENT

G3-3.1 Seabrook Impingement and Entrainment Monitoring

Seabrook has sampled impinged organisms since 1990 (Normandeau Associates, 1990, 1991, 1993, 1994a, 1994b, 1995, 1996a, 1996b, 1997, 1999). Impinged fish are collected after being washed from the 9.525 mm mesh traveling screens within the circulating water pumphouse. Before 1998, screens were washed once per week, or more frequently during storm conditions, and collected fish were identified to species and counted (Normandeau Associates, 1999). Because of inadequate removal of small fish from screenwash debris, the facility believes that estimates from 1990 to 1994 are likely to be underestimated (Normandeau Associates, 1995). Prior to 1998, the number of fish impinged in unassessed screenwashes was estimated based on the volume of debris in the unassessed screenwash and the volume of debris in the assessed screenwash nearest in time to the collection date. The sum of assessed screenwashes and the calculated value for the unassessed screenwashes allowed calculation of an annual estimate of fish impinged (Normandeau Associates, 1997, 1999). In 1998 sampling procedures were adjusted so that traveling screens were washed at least twice each week and fish were counted in every screenwash. Since 1998, the annual impingement is the sum of the fish impinged from every screenwash (Normandeau Associates, 1999; R. Sher, Seabrook Station, personal communication, 2001).

G3-3.2 Seabrook Entrainment Monitoring

Seabrook has also conducted entrainment sampling since 1990 (Normandeau Associates, 1990, 1991, 1993, 1994b, 1995, 1996a, 1996b, 1997, 1999; Saila et al., 1997). Samples are collected with 0.505 mm mesh nets suspended in double-barrel

collection devices. Initially, three replicate samples were taken once during the day on each sampling date, but beginning in January 1998 the sampling design changed to include 24-hour sampling. Samples are taken four times each month, and in four diel periods (2400-0600, 0600-1200, 1200-1800, 1800-2400 hours). The weekly number of entrained organisms is estimated by calculating the arithmetic mean density in a sample for each sampling day and multiplying by the cooling water volume during the week the sample was taken. These weekly estimates are summed for a monthly estimate, and monthly estimates are summed to derive an annual estimate (Normandeau Associates, 1997). Slight variations in annual extrapolations methods can be found in Seabrook facility documents for previous years (Normandeau Associates, 1993, 1994a, 1995).

G3-4 SEABROOK'S ANNUAL IMPINGEMENT AND ENTRAINMENT

EPA evaluated annual impingement and entrainment at Seabrook using the methods described in Chapter A5 of Part A of this document.[1] The species-specific life history values used by EPA for its analyses are presented in Appendix G1. Table G3-2 displays facility estimates of annual impingement (numbers of organisms) at the Seabrook facility, by species. Table G3-3 displays those numbers expressed as age 1 equivalents, Table G3-4 displays impingement of fishery species as yield lost to fisheries, and Table G3-5 displays impingement expressed as production foregone. Tables G3-6 through G3-9 display the same information for entrainment at Seabrook.

G3-5 PILGRIM'S METHODS FOR ESTIMATING IMPINGEMENT AND ENTRAINMENT

G3-5.1 Pilgrim Impingement and Entrainment Monitoring

Impingement monitoring at Pilgrim has been conducted three times per week since 1974. Traveling screens are washed over a 24-hour period, once in the morning, once in the afternoon, and once at night. To estimate annual impingement numbers, Pilgrim divides the numbers of fish impinged during an impingement monitoring period by the numbers of hours of monitoring, and then the resulting impingement rate per hour is multiplied by 24 hours and by 365 days to obtain an annual number. After 1990, if all four intake screens were not washed, then the number of fish impinged was increased by a proportional factor (Boston Edison Company, 1991-1994, 1995a, 1995b, 1996-1999; Entergy Nuclear General Company, 2000).

G3-5.2 Pilgrim Entrainment Monitoring

Entrainment sampling at Pilgrim began in 1974 (Boston Edison Company, 1991-1994, 1995a, 1995b, 1996-1999; Entergy Nuclear General Company, 2000). Samples are taken in triplicate at low tide. In most years sampling was twice a month from October through February and weekly from March through September. However, this regime was modified in 1994. Sampling from October through February now involves taking single samples on three separate occasions during two alternate weeks each month. The standard mesh is 0.333 mm, except from late March through late May, when a 0.202 mm mesh is used. From March through September single samples are taken three times every week. All sampling is done with a 60 cm diameter plankton net fitted with a digital flow meter. This allows for calculation of arithmetic mean densities of larvae and eggs entrained. Annual numbers of entrainment were determined using the full load capacity of the plant (Entergy Nuclear Generating Company, 2001).

G3-6 PILGRIM'S ANNUAL IMPINGEMENT AND ENTRAINMENT

EPA evaluated annual impingement and entrainment at Pilgrim using the methods described in Chapter A5 of Part A of this document.[1] The species-specific life history values used by EPA for its analyses were the same as those used to evaluate Seabrook's losses and are presented in Appendix G1. Table G3-10 displays facility estimates of annual impingement (numbers of organisms) at the Pilgrim facility, by species. Table G3-11 displays those numbers expressed as age 1 equivalents, Table G3-12 displays impingement of fishery species as yield lost to fisheries, and Table G3-13 displays the Seabrook annual impingement expressed as production foregone. Tables G3-14 through G3-17 display the same information for entrainment at Pilgrim.

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[1] In some cases the facility did not identify impinged or entrained organisms at the species level or life history data were not available for different species in the same family. In these cases, EPA grouped the losses together under a single species.

Table G3-2: Annual Impingement (numbers of organisms) at Seabrook, By Species, as Estimated by the Facility

Year	Alewife	American Lobster	American Plaice	American Sand Lance	Atlantic Cod	Atlantic Herring	Atlantic Mackerel	Atlantic Moonfish	Atlantic Silverside	Atlantic Torpedo	Black Sea Bass	Blueback Herring
1990	0	4	0	3	18	44	4	0	0	0	0	0
1991	1	29	0	0	28	8	13	0	8	0	1	0
1992	0	8	0	28	26	22	3	0	67	0	0	0
1993	1	1	1	3	37	19	0	0	156	0	0	0
1994	0	31	0	1,215	59	514	0	0	5,348	0	0	13
1995	8	16	0	1,324	120	231	0	3	1,621	1	3	0
1996	1,753	31	0	823	491	577	1	0	1,119	5	0	111
1997	2,797	20	0	182	69	589	0	0	210	0	0	323
1998	14	4	0	708	39	583	0	1	834	0	3	7
Mean	508	16	0	476	99	287	2	0	1,040	1	1	50
Minimum	0	1	0	0	18	8	0	0	0	0	0	0
Maximum	2,797	31	1	1,324	491	589	13	3	5,348	5	3	323
SD	1,035	12	0	548	150	273	4	1	1,714	2	1	108
Total	4,574	144	1	4,286	887	2,587	21	4	9,363	6	7	454

NA=Not sampled.
0=Sampled, but none collected.
Mon Feb 11 07:56:36 MST 2002 Raw.losses. IMPINGEMENT; Plant:seabrook.90.98;
PATHNAME:P:/Intake/Seabrook-Pilgrim/Science/scode/seabrook/tables.output.90.98.no.mussel/raw.losses.imp.seabrook.90.98.csv

Table G3-2: Annual Impingement (numbers of organisms) at Seabrook, By Species, as Estimated by the Facility (cont.)

Year	Butterfish	Conger Eel	Cunner	Fourbeard Rockling	Goosefish	Grubby	Little Skate	Lumpfish	Northern Kingfish	Northern Pipefish	Northern Puffer	Ocean Pout	Oyster Toadfish	Planehead Filefish
1990	0	0	21	0	1	11	12	69	0	0	0	1	1	0
1991	0	1	2	1	0	26	105	96	1	6	0	2	0	0
1992	2	0	13	1	0	54	48	35	0	2	0	3	0	0
1993	0	0	13	0	0	67	35	131	0	83	0	0	0	0
1994	3	0	32	0	3	2,678	190	362	0	188	0	0	0	0
1995	14	0	342	6	13	2,415	157	355	0	579	0	6	0	15
1996	3	0	1,121	19	0	1,457	225	1,064	2	1,200	0	1	0	0
1997	223	0	233	0	0	430	177	413	0	243	5	0	0	0
1998	9	0	309	3	7	3,269	41	993	0	268	0	7	0	0
Mean	28	0	232	3	3	1,156	110	391	0	285	1	2	0	2
Minimum	0	0	2	0	0	11	12	35	0	0	0	0	0	0
Maximum	223	1	1,121	19	13	3,269	225	1,064	2	1,200	5	7	1	15
SD	73	0	361	6	5	1,322	79	388	1	390	2	3	0	5
Total	254	1	2,086	30	24	10,407	990	3,518	3	2,569	5	20	1	15

0=Sampled, but none collected.
Mon Feb 11 07:56:36 MST 2002 Raw.losses. IMPINGEMENT; Plant:seabrook.90.98;
PATHNAME:P:/Intake/Seabrook-Pilgrim/Science/scode/seabrook/tables.output.90.98.no.mussel/raw.losses.imp.seabrook.90.98.csv

Table G3-2: Annual Impingement (numbers of organisms) at Seabrook, By Species, as Estimated by the Facility (cont.)

Year	Pollock	Radiated Shanny	Rainbow Smelt	Red Hake	Rock Gunnel	Rough Scad	Sand Tiger	Sculpin Spp.	Scup	Sea Lamprey	Seal	Searobin	Spiny Dogfish
1990	69	4	0	16	14	0	0	109	0	1	0	10	1
1991	124	1	12	55	11	3	0	143	1	5	0	12	2
1992	231	0	67	16	40	0	0	161	0	3	0	1	1
1993	32	0	80	5	25	0	0	170	0	6	0	1	0
1994	1,681	0	545	2,824	494	0	0	402	0	0	6	0	1
1995	899	92	213	2,269	1,298	0	0	446	14	0	6	0	0
1996	1,835	40	4,489	2,659	1,122	0	57	1,381	9	1	0	0	6
1997	379	2	365	601	459	0	0	434	0	6	0	11	0
1998	536	39	535	926	2,929	0	0	365	3	7	0	1	0
Mean	643	20	701	1,041	710	0	6	401	3	3	1	4	1
Minimum	32	0	0	5	11	0	0	109	0	0	0	0	0
Maximum	1,835	92	4,489	2,824	2,929	3	57	1,381	14	7	6	12	6
SD	688	32	1,436	1,207	964	1	19	392	5	3	3	5	2
Total	5,786	178	6,306	9,371	6,392	3	57	3,611	27	29	12	36	11

0=Sampled, but none collected.
Mon Feb 11 07:56:36 MST 2002 Raw.losses. IMPINGEMENT; Plant:seabrook.90.98;
PATHNAME:P:/Intake/Seabrook-Pilgrim/Science/scode/seabrook/tables.output.90.98.no.mussel/raw.losses.imp.seabrook.90.98.csv

Table 63-2: Annual Impingement (numbers of organisms) at Seabrook, By Species, as Estimated by the Facility (cont.)

Year	Striped Anchovy	Striped Bass	Striped Cusk Eel	Striped Killifish	Tautog	Threespine Stickleback	Unidentified	White Perch	Windowpane	Winter Flounder	Wolffish	Wrymouth
1990	1	0	0	0	3	0	4	1	54	21	0	5
1991	0	0	0	0	9	3	4	0	155	134	1	15
1992	0	0	0	0	9	3	5	0	97	209	0	16
1993	0	0	0	0	3	17	0	0	103	205	0	12
1994	0	0	0	4	0	67	6	0	985	1,512	0	55
1995	0	4	0	0	0	155	40	0	944	2,323	2	9
1996	0	1	0	47	34	320	88	4	1,168	3,239	13	206
1997	0	0	3	24	0	174	49	0	1,691	491	0	3
1998	0	0	0	0	3	798	0	1	776	1,156	1	21
Mean	0	1	0	8	7	171	22	1	664	1,032	2	38
Minimum	0	0	0	0	0	0	0	0	54	21	0	3
Maximum	1	4	3	47	34	798	88	4	1,691	3,239	13	206
SD	0	1	1	16	11	259	31	1	588	1,133	4	65
Total	1	5	3	75	61	1,537	196	6	5,973	9,290	17	342

0=Sampled, but none collected.

Mon Feb 11 07:56:36 MST 2002 Raw.losses. IMPINGEMENT; Plant:seabrook.90.98;

PATHNAME:P:/Intake/Seabrook-Pilgrim/Science/scode/seabrook/tables.output.90.98.no.mussel/raw.losses.imp.seabrook.90.98.csv

Table G3-3: Annual Impingement at Seabrook, by Species, Expressed as Age 1 Equivalents

Year	Alewife	American Plaice	American Sand Lance	Atlantic Cod	Atlantic Herring	Atlantic Mackerel	Atlantic Menhaden	Atlantic Silverside	Blueback Herring	Butter-fish	Cunner	Fourbeard Rockling	Grubby	Little Skate	Lump-fish
1990	0	0	4	22	51	5	0	0	0	0	29	0	13	15	76
1991	1	0	0	34	9	16	0	14	0	0	3	1	32	135	105
1992	0	0	41	31	26	4	0	121	0	3	18	1	66	62	38
1993	1	1	4	44	22	0	0	281	0	0	18	0	82	45	143
1994	0	0	1,776	71	598	0	0	9,620	15	4	45	0	3,283	244	396
1995	11	0	1,936	144	269	0	9	2,916	0	19	476	7	2,961	201	389
1996	2,343	0	1,203	588	671	1	118	2,013	128	4	1,562	24	1,786	288	1,165
1997	3,738	0	266	83	685	0	0	378	371	299	325	0	527	227	452
1998	19	0	1,035	47	678	0	1	1,500	8	12	430	4	4,008	53	1,087
Mean	679	0	696	118	334	3	14	1,871	58	38	323	4	1,418	141	428
Minimum	0	0	0	22	9	0	0	0	0	0	3	0	13	15	38
Maximum	3,738	1	1,936	588	685	16	118	9,620	371	299	1,562	24	4,008	288	1,165
SD	1,383	0	801	180	318	5	39	3,084	125	98	503	8	1,620	102	425
Total	6,113	1	6,267	1,062	3,010	26	128	16,842	522	341	2,906	37	12,759	1,269	3,851

Note: Impingement losses expressed as age 1 equivalents are larger than raw losses (the actual number of organisms impinged). This is because the ages of impinged individuals are assumed to be distributed across the interval between the start of year 1 and the start of year 2, and then the losses are normalized back to the start of year 1 by accounting for mortality during this interval (for details, see description of S*j in Chapter A2, Equation 4 and Equation 5). This type of adjustment is applied to all raw loss records, but the effect is not readily apparent among entrainment losses because the majority of entrained fish are younger than age 1.

0=Sampled, but none collected.

Fri Feb 08 09:49:55 MST 2002 ;Results; I Plant: seabrook.90.98 ; Units: equivalent.sums Pathname: P:/Intake/Seabrook-Pilgrim/Science/scode/seabrook/tables.output.90.98.no.mussel/I.equivalent.sums.seabrook.90.98.csv

Table G3-3: Annual Impingement at Seabrook, by Species, Expressed as Age 1 Equivalents (cont.)

Year	Northern Pipefish	Pollock	Radiated Shanny	Rainbow Smelt	Red Hake	Rock Gunnel	Sculpin Spp.	Scup	Sea-robin	Striped Bass	Striped Killifish	Tautog	Threespine Stickleback	White Perch	Window-pane	Winter Flounder
1990	0	76	5	0	20	17	134	0	12	0	0	3	0	1	65	23
1991	8	136	1	16	70	13	175	1	15	0	0	10	4	0	186	147
1992	3	254	0	91	20	49	197	0	1	0	0	10	4	0	116	230
1993	113	35	0	108	6	30	208	0	1	0	0	3	24	0	124	226
1994	255	1,849	0	738	3,616	601	493	0	0	0	5	0	95	0	1,182	1,664
1995	786	989	112	288	2,905	1,579	547	16	0	6	0	0	220	0	1,133	2,557
1996	1,630	2,018	49	6,078	3,404	1,365	1,693	11	0	1	64	37	455	5	1,402	3,565
1997	330	417	2	494	769	558	532	0	14	0	33	0	247	0	2,030	540
1998	364	589	47	724	1,186	3,563	448	4	1	0	0	3	1,135	1	931	1,272
Mean	388	707	24	949	1,333	864	492	4	5	1	11	7	243	1	797	1,136
Minimum	0	35	0	0	6	13	134	0	0	0	0	0	0	0	65	23
Maximum	1,630	2,018	112	6,078	3,616	3,563	1,693	16	15	6	64	37	1,135	5	2,030	3,565
SD	529	757	39	1,945	1,546	1,173	480	6	7	2	23	12	368	2	706	1,247
Total	3,490	6,363	217	8,538	11,998	7,776	4,427	32	44	7	103	67	2,185	8	7,169	10,226

Note: Impingement losses expressed as age 1 equivalents are larger than raw losses (the actual number of organisms impinged). This is because the ages of impinged individuals are assumed to be distributed across the interval between the start of year 1 and the start of year 2, and then the losses are normalized back to the start of year 1 by accounting for mortality during this interval (for details, see description of S*j in Chapter A2, Equation 4 and Equation 5). This type of adjustment is applied to all raw loss records, but the effect is not readily apparent among entrainment losses because the majority of entrained fish are younger than age 1.
0=Sampled, but none collected.
Fri Feb 08 09:49:55 MST 2002 ;Results; I Plant: seabrook.90.98 ; Units: equivalent.sums Pathname: P:/Intake/Seabrook-
Pilgrim/Science/scode/seabrook/tables.output.90.98.no.mussel/I.equivalent.sums.seabrook.90.98.csv

Table G3-4: Annual Impingement of Fishery Species at Seabrook Expressed as Yield Lost to Fisheries (in pounds)

Year	Alewife	Atlantic Cod	Atlantic Herring	Atlantic Mackerel	Atlantic Menhaden	Atlantic Silverside	Blueback Herring	Butterfish	Cunner	Little Skate	Pollock
1990	0	7	7	1	0	0	0	0	0	3	111
1991	0	11	1	2	0	0	0	0	0	28	200
1992	0	10	4	1	0	0	0	0	0	13	373
1993	0	15	3	0	0	0	0	0	0	9	52
1994	0	23	83	0	0	4	0	0	0	50	2,713
1995	0	47	37	0	3	1	0	1	2	42	1,451
1996	12	192	93	0	41	1	1	0	7	60	2,962
1997	19	27	95	0	0	0	3	14	1	47	612
1998	0	15	94	0	0	1	0	1	2	11	865
Mean	3	39	46	0	5	1	0	2	1	29	1,038
Minimum	0	7	1	0	0	0	0	0	0	3	52
Maximum	19	192	95	2	41	4	3	14	7	60	2,962
SD	7	59	44	1	13	1	1	5	2	21	1,111
Total	31	348	417	4	44	7	4	16	13	262	9,340

0=Sampled, but none collected.
Fri Feb 08 09:50:05 MST 2002 ;Results; 1 Plant: seabrook.90.98 ; Units: yield Pathname: P:/Intake/Seabrook-Pilgrim/Science/scode/seabrook/tables.output.90.98.no.mussel/l.yield.seabrook.90.98.csv

Table G3-4: Annual Impingement of Fishery Species at Seabrook Expressed as Yield Lost to Fisheries (in pounds) (cont.)

Year	Rainbow Smelt	Red Hake	Scup	Searobin	Striped Bass	Tautog	Windowpane	Winter Flounder
1990	0	4	0	1	0	4	5	7
1991	0	13	0	1	0	11	14	46
1992	1	4	0	0	0	11	9	73
1993	1	1	0	0	0	4	9	71
1994	6	644	0	0	0	0	87	525
1995	2	518	3	0	8	0	84	806
1996	45	607	2	0	2	41	103	1,124
1997	4	137	0	1	0	0	150	170
1998	5	211	1	0	0	4	69	401
Mean	7	238	1	0	1	8	59	358
Minimum	0	1	0	0	0	0	5	7
Maximum	45	644	3	1	8	41	150	1,124
SD	15	275	1	0	3	13	52	393
Total	64	2,138	6	2	10	74	529	3,223

0=Sampled, but none collected.
Fri Feb 08 09:50:05 MST 2002 ;Results; I Plant: seabrook.90.98 ; Units: yield Pathname: P:/Intake/Seabrook-
Pilgrim/Science/scode/seabrook/tables.output.90.98.no.mussel/I.yield.seabrook.90.98.csv

Table G3-5: Annual Impingement at Seabrook, By Species, Expressed as Production Foregone (in pounds)

Year	Alewife	American Sand Lance	Atlantic Cod	Atlantic Herring	Atlantic Mackerel	Atlantic Menhaden	Atlantic Silverside	Blueback Herring	Butterfish	Cunner	Grubby	Little Skate	Lumpfish	Northern Pipefish
1990	0	0	2	4	0	0	0	0	0	0	1	1	2	0
1991	0	0	4	1	1	0	0	0	0	0	2	13	3	0
1992	0	0	4	2	0	0	0	0	0	0	4	6	1	0
1993	0	0	5	2	0	0	0	0	0	0	5	4	5	0
1994	0	9	8	47	0	0	3	1	0	0	200	23	13	0
1995	0	10	16	21	0	1	1	0	0	3	180	19	13	1
1996	73	6	67	52	0	19	1	6	0	9	109	28	38	2
1997	117	1	9	54	0	0	0	17	7	2	32	22	15	0
1998	1	5	5	53	0	0	1	0	0	2	244	5	35	0
Mean	21	4	13	26	0	2	1	3	1	2	86	14	14	0
Minimum	0	0	2	1	0	0	0	0	0	0	1	1	1	0
Maximum	117	10	67	54	1	19	3	17	7	9	244	28	38	2
SD	43	4	21	25	0	6	1	6	2	3	99	10	14	1
Total	191	33	121	235	2	20	6	24	8	16	776	122	124	4

0=Sampled, but none collected.
Fri Feb 08 09:50:00 MST 2002 ;Results; I Plant: seabrook.90.98 ; Units: annual.prod.forg Pathname: P:/Intake/Seabrook-Pilgrim/Science/scode/seabrook/tables.output.90.98.no.mussel/I.annual.prod.forg.seabrook.90.98.csv

Table G3-5: Annual Impingement at Seabrook, By Species, Expressed as Production Foregone (in pounds) (cont.)

Year	Pollock	Rainbow Smelt	Red Hake	Rock Gunnel	Sculpin Spp.	Scup	Searobin	Striped Bass	Tautog	Windowpane	Winter Flounder
1990	36	0	3	0	8	0	1	0	0	1	3
1991	64	0	10	0	11	0	1	0	1	3	18
1992	119	3	3	0	12	0	0	0	1	2	28
1993	17	3	1	0	13	0	0	0	0	2	27
1994	868	23	494	3	30	0	0	0	0	21	201
1995	464	9	397	7	33	2	0	2	0	20	309
1996	948	186	465	6	103	1	0	0	5	25	431
1997	196	15	105	3	32	0	1	0	0	36	65
1998	277	22	162	16	27	0	0	0	0	17	154
Mean	332	29	182	4	30	0	0	0	1	14	137
Minimum	17	0	1	0	8	0	0	0	0	1	3
Maximum	948	186	494	16	103	2	1	2	5	36	431
SD	355	60	211	5	29	1	0	1	1	13	151
Total	2,988	262	1,640	35	269	3	3	2	7	128	1,236

0=Sampled, but none collected.

Fri Feb 08 09:50:00 MST 2002 ;Results; I Plant: seabrook.90.98 ; Units: annual.prod.forg Pathname: P:/Intake/Seabrook-Pilgrim/Science/scode/seabrook/tables.output.90.98.no.mussel/I.annual.prod.forg.seabrook.90.98.csv

Table G3-6: Annual Entrainment (numbers of organisms) at Seabrook, By Species, as Estimated by the Facility

Year	Alligator-fish	American Eel	American Plaice	American Sand Lance	Atlantic Cod	Atlantic Herring	Atlantic Mackerel	Atlantic Menhaden	Blue Mussel	Bluefish	Butterfish	Cunner
1990	0	0	3,000,000	0	3,200,000	700,000	519,000,000	100,000	3,991,300,000,000	0	0	42,700,000
1991	100,000	0	22,000,000	37,300,000	1,500,000	500,000	677,800,000	500,000	1,687,400,000,000	0	0	50,000
1992	200,000	0	53,100,000	18,100,000	3,000,000	4,900,000	456,300,000	1,400,000	121,900,000,000	0	0	0
1993	0	0	20,200,000	12,000,000	50,400,000	9,600,000	112,900,000	100,000	10,050,700,000,000	0	0	4,700,000
1994	200,000	0	400,000	8,300,000	500,000	100,000	0	0	NA	0	0	100,000
1995	300,000	0	22,700,000	9,500,000	6,900,000	11,200,000	74,500,000	200,000	13,231,000,000,000	0	300,000	4,400,000
1996	100,000	0	86,300,000	14,000,000	9,800,000	4,300,000	305,200,000	100,000	17,931,800,000,000	0	200,000	9,200,000
1997	100,000	0	22,600,000	10,100,000	3,800,000	2,100,000	23,500,000	200,000	1,744,500,000,000	100,000	0	239,700,000
1998	174,000	14,000	16,623,000	10,662,000	10,970,000	9,506,000	39,316,000	114,000	1,493,030,000,000	0	0	17,783,000
Mean	130,444	1,556	27,435,889	13,329,111	10,007,778	4,767,333	245,390,667	301,556	6,281,453,750,000	11,111	55,556	35,403,667
Minimum	0	0	400,000	0	500,000	100,000	0	0	121,900,000,000	0	0	0
Maximum	300,000	14,000	86,300,000	37,300,000	50,400,000	11,200,000	677,800,000	1,400,000	17,931,800,000,000	100,000	300,000	239,700,000
SD	98,193	4,667	26,684,083	10,214,826	15,568,118	4,345,642	252,134,888	435,111	6,612,079,486,100	33,333	113,039	77,814,636
Total	1,174,000	14,000	246,923,000	119,962,000	90,070,000	42,906,000	2,208,516,000	2,714,000	50,251,630,000,000	100,000	500,000	318,633,000

NA=Not sampled.
0=Sampled, but none collected.
Mon Feb 11 07:56:41 MST 2002 Raw.losses. ENTRAINMENT; Plant:seabrook.90.98;
PATHNAME:P:/Intake/Seabrook-Pilgrim/Science/scode/seabrook/tables.output.90.98.no.mussel/raw.losses.ent.seabrook.90.98.csv

Table G3-6: Annual Entrainment (numbers of organisms) at Seabrook, By Species, as Estimated by the Facility (cont.)

Year	Fourbeard Rockling	Goosefish	Grubby	Lumpfish	Northern Pipefish	Other	Pollock	Radiated Shanny	Rainbow Smelt	Red Hake	Redfish	Rock Gunnel	Sculpin Spp.
1990	159,600,000	100,000	0	12,400,000	0	0	203,550	4,800,000	200,000	61,200,000	0	0	0
1991	40,400,000	0	22,400,000	19,200,000	0	100,000	1,000,000	3,100,000	0	2,600,000	0	51,100,000	900,000
1992	51,500,000	0	18,900,000	33,500,000	0	300,000	465,964	1,100,000	100,000	100,000	400,000	45,300,000	1,600,000
1993	36,400,000	0	13,800,000	76,900,000	0	0	200,000	200,000	0	800,000	0	5,700,000	1,000,000
1994	1,900,000	0	4,900,000	3,600,000	0	2,000,000	100,000	0	0	1,000,000	50,000	11,000,000	2,600,000
1995	35,800,000	0	17,400,000	33,300,000	0	2,100,000	400,000	2,100,000	0	49,200,000	0	15,600,000	900,000
1996	81,400,000	300,000	18,600,000	65,100,000	100,000	0	400,000	2,000,000	100,000	286,800,000	0	33,800,000	2,600,000
1997	72,400,000	0	12,800,000	2,300,000	0	0	200,000	300,000	0	410,400,000	0	25,100,000	2,150,000
1998	47,193,000	886,000	17,315,000	40,466,000	0	0	2,974,000	1,702,000	228,000	26,267,000	0	16,872,000	2,960,000
Mean	58,510,333	142,889	14,012,778	31,862,889	11,111	500,000	660,390	1,700,222	69,778	93,151,889	50,000	22,719,111	1,634,444
Minimum	1,900,000	0	0	2,300,000	0	0	100,000	0	0	100,000	0	0	0
Maximum	159,600,000	886,000	22,400,000	76,900,000	100,000	2,100,000	2,974,000	4,800,000	228,000	410,400,000	400,000	51,100,000	2,960,000
SD	44,230,288	296,066	7,233,324	26,037,747	33,333	884,590	907,482	1,552,418	92,306	149,771,232	132,288	17,577,835	1,002,586
Total	526,593,000	1,286,000	126,115,000	286,766,000	100,000	4,500,000	5,943,514	15,302,000	628,000	838,367,000	450,000	204,472,000	14,710,000

NA=Not sampled.

0=Sampled, but none collected.

Mon Feb 11 07:56:41 MST 2002 Raw.losses. ENTRAINMENT; Plant:seabrook.90.98;

PATHNAME:P:/Intake/Seabrook-Pilgrim/Science/scode/seabrook/tables.output.90.98.no.mussel/raw.losses.ent.seabrook.90.98.csv

Table G3-6: Annual Entrainment (numbers of organisms) at Seabrook, By Species, as Estimated by the Facility (cont.)

Year	Searobin	Tautog	Unidentified	Windowpane	Winter Flounder	Wrymouth
1990	0	300,000	700,000	40,400,000	520,479,242	0
1991	0	200,000	4,100,000	19,950,000	800,030,734	100,000
1992	0	0	1,400,000	22,600,000	242,018,538	0
1993	0	0	6,300,000	29,200,000	62,666,462	0
1994	0	0	800,000	200,000	500,000	0
1995	0	0	36,800,000	19,400,000	60,200,044	0
1996	100,000	500,000	3,300,000	46,200,000	172,100,000	0
1997	0	100,000	4,400,000	34,200,000	199,800,000	0
1998	0	56,000	594,000	19,390,000	138,521,000	0
Mean	11,111	128,444	6,488,222	25,726,667	244,035,113	11,111
Minimum	0	0	594,000	200,000	500,000	0
Maximum	100,000	500,000	36,800,000	46,200,000	800,030,734	100,000
SD	33,333	174,876	11,541,012	13,662,276	257,347,153	33,333
Total	100,000	1,156,000	58,394,000	231,540,000	2,196,316,020	100,000

NA=Not sampled.
0=Sampled, but none collected.
Mon Feb 11 07:56:41 MST 2002 Raw.losses. ENTRAINMENT; Plant:seabrook.90.98;
PATHNAME:P:/Intake/Seabrook-Pilgrim/Science/scode/seabrook/tables.output.90.98.no.mussel/raw.losses.ent.seabrook.90.98.csv

Table 63-7: Annual Entrainment at Seabrook, By Species, Expressed as Age 1 Equivalents

Year	American Plaice	American Sand Lance	Atlantic Cod	Atlantic Herring	Atlantic Mackerel	Atlantic Menhaden	Bluefish	Butterfish	Cunner	Fourbeard Rockling	Grubby	Lumpfish
1990	137	0	1,682	2,041	2,188	38	0	0	257,980	553,743	0	2,063
1991	628	1,112,394	3,509	1,458	3,061	21	0	0	302	46,849	402,989	3,195
1992	1,198	539,795	1,214	14,287	1,915	59	0	0	0	54,207	340,022	5,574
1993	533	357,875	1,134	27,991	474	4	0	0	28,396	60,164	248,270	11,358
1994	8	247,530	9	292	0	0	0	0	604	1,962	88,154	584
1995	1,995	283,318	5,463	32,656	313	8	0	178	26,583	76,991	313,036	4,633
1996	3,281	417,521	872	12,538	1,286	4	0	65	55,584	204,123	334,624	10,650
1997	1,816	301,211	1,693	6,123	117	8	5	0	1,237,732	304,634	230,279	337
1998	904	317,972	5,392	27,717	165	22	0	0	52,661	183,680	311,507	6,733
Mean	1,167	397,513	2,330	13,900	1,058	18	1	27	184,427	165,150	252,098	5,014
Minimum	8	0	9	292	0	0	0	0	0	1,962	0	337
Maximum	3,281	1,112,394	5,463	32,656	3,061	59	5	178	1,237,732	553,743	402,989	11,358
SD	1,045	304,636	1,987	12,671	1,105	19	2	60	403,080	174,661	130,132	4,015
Total	10,501	3,577,615	20,969	125,103	9,518	166	5	242	1,659,842	1,486,353	2,268,880	45,127

0=Sampled, but none collected.

Fri Feb 08 09:49:51 MST 2002 ;Results; E Plant: seabrook.90.98 ; Units: equivalent.sums Pathname: P:/Intake/Seabrook-Pilgrim/Science/scode/seabrook/tables.output.90.98.no.mussel/E.equivalent.sums.seabrook.90.98.csv

Table G3-7: Annual Entrainment at Seabrook, By Species, Expressed as Age 1 Equivalents (cont.)

Year	Northern Pipefish	Pollock	Radiated Shanny	Rainbow Smelt	Red Hake	Rock Gunnel	Sculpin Spp.	Searobin	Tautog	Windowpane	Winter Flounder
1990	0	7	409,203	26,168	219	0	0	0	35	19,939	71,318
1991	0	9	264,277	0	12	7,237,775	16,192	0	2	4,266	136,415
1992	0	6	93,776	13,084	0	6,416,266	28,785	0	0	4,958	56,990
1993	0	2	17,050	0	3	807,345	17,991	0	0	6,322	38,359
1994	0	1	0	0	5	1,558,034	46,775	0	0	331	8
1995	0	4	179,026	0	214	2,209,575	16,192	0	0	9,804	64,212
1996	7,034	4	170,501	486	1,159	4,787,413	46,775	2,044	26	15,340	197,222
1997	0	2	25,575	0	1,529	3,555,150	38,680	0	1	23,585	53,898
1998	0	29	145,097	29,832	117	2,389,740	53,252	0	0	8,306	83,990
Mean	782	7	144,945	7,730	362	3,217,922	29,405	227	7	10,317	78,046
Minimum	0	1	0	0	0	0	0	0	0	331	8
Maximum	7,034	29	409,203	29,832	1,529	7,237,775	53,252	2,044	35	23,585	197,222
SD	2,345	9	132,345	12,290	571	2,489,715	18,037	681	13	7,739	57,634
Total	7,034	64	1,304,505	69,571	3,258	28,961,298	264,641	2,044	64	92,851	702,411

0=Sampled, but none collected.

Fri Feb 08 09:49:51 MST 2002 ;Results; E Plant: seabrook.90.98 ; Units: equivalent.sums Pathname: P:/Intake/Seabrook-Pilgrim/Science/scode/seabrook/tables.output.90.98.no.mussel/E.equivalent.sums.seabrook.90.98.csv

Table 63-8: Annual Entrainment of Fishery Species at Seabrook Expressed as Yield Lost to Fisheries (in pounds)

Year	American Plaice	Atlantic Cod	Atlantic Herring	Atlantic Mackerel	Atlantic Menhaden	Bluefish	Butter-fish	Cunner	Pollock	Rainbow Smelt	Red Hake	Sea-robin	Tautog	Window-pane	Winter Flounder
1990	16	551	283	303	13	0	0	1,163	10	196	39	0	39	1,470	22,481
1991	72	1,149	202	423	7	0	0	1	14	0	2	0	2	314	43,002
1992	137	398	1,980	265	20	0	0	0	9	98	0	0	0	366	17,965
1993	61	371	3,879	66	1	0	0	128	3	0	0	0	0	466	12,092
1994	1	3	40	0	0	0	0	3	1	0	1	0	0	24	2
1995	228	1,788	4,526	43	3	0	9	120	6	0	38	0	0	723	20,241
1996	376	285	1,738	178	1	0	3	251	6	4	207	102	29	1,131	62,170
1997	208	554	849	16	3	3	0	5,582	3	0	272	0	1	1,739	16,990
1998	104	1,765	3,842	23	8	0	0	237	43	223	21	0	1	612	26,476
Mean	134	763	1,927	146	6	0	1	832	10	58	65	11	8	761	24,602
Minimum	1	3	40	0	0	0	0	0	1	0	0	0	0	24	2
Maximum	376	1,788	4,526	423	20	3	9	5,582	43	223	272	102	39	1,739	62,170
SD	120	651	1,756	153	7	1	3	1,818	13	92	102	34	15	571	18,168
Total	1,202	6,864	17,339	1,316	57	3	12	7,486	93	521	581	102	71	6,845	221,419

0=Sampled, but none collected.

Fri Feb 08 09:50:03 MST 2002 ;Results; E Plant: seabrook.90.98 ; Units: yield Pathname: P:/Intake/Seabrook-Pilgrim/Science/scode/seabrook/tables.output.90.98.no.mussel/E.yield.seabrook.90.98.csv

Table G3-9: Annual Entrainment at Seabrook, By Species, Expressed as Production Foregone (in pounds)

Year	American Plaice	American Sand Lance	Atlantic Cod	Atlantic Herring	Atlantic Mackerel	Atlantic Menhaden	Butterfish	Cunner	Fourbeard Rockling	Grubby	Lumpfish	Northern Pipefish
1990	53	0	318	827	3,789	0	0	4,552	13,170	0	9,946	0
1991	282	41,799	662	591	5,286	0	0	5	1,123	39,707	15,400	0
1992	595	20,283	230	5,788	3,318	0	0	0	1,300	33,503	26,869	0
1993	247	13,448	227	11,340	821	0	0	501	1,437	24,462	57,172	0
1994	2	9,301	2	118	0	0	0	11	47	8,686	2,840	0
1995	68	10,646	1,031	13,230	542	14	27	469	1,835	30,844	23,863	0
1996	357	15,689	167	5,080	2,227	7	10	981	4,862	32,971	51,645	268
1997	71	11,318	320	2,481	201	14	0	21,853	7,240	22,690	1,702	0
1998	62	11,948	1,019	11,229	286	36	0	932	4,367	30,693	32,456	0
Mean	193	14,937	442	5,632	1,830	8	4	3,256	3,931	24,840	24,655	30
Minimum	2	0	2	118	0	0	0	0	47	0	1,702	0
Maximum	595	41,799	1,031	13,230	5,286	36	27	21,853	13,170	39,707	57,172	268
SD	195	11,447	374	5,133	1,911	12	9	7,116	4,151	12,822	19,865	89
Total	1,736	134,433	3,974	50,684	16,470	71	37	29,304	35,380	223,557	221,893	268

0=Sampled, but none collected.

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Pilgrim/Science/scode/seabrook/tables.output.90.98.no.mussel/E.annual.prod.forg.seabrook.90.98.csv

Table G3-9: Annual Entrainment at Seabrook, By Species, Expressed as Production Foregone (in pounds) (cont.)

Year	Pollock	Radiated Shanny	Rainbow Smelt	Red Hake	Rock Gunnel	Sculpin Spp.	Searobin	Tautog	Windowpane	Winter Flounder
1990	3,231	1,356	3,325	3,041,125	0	0	0	10	1,214	50,876
1991	4,595	876	0	162,360	79,348	1,595	0	1	287	97,314
1992	2,885	311	1,662	6,245	70,342	2,836	0	0	332	40,657
1993	919	57	0	37,468	8,851	1,773	0	0	424	27,360
1994	459	0	0	62,446	17,081	4,609	0	0	19	385
1995	1,838	593	0	2,972,435	24,224	1,595	0	0	596	45,800
1996	1,838	565	90	16,086,117	52,485	4,609	279	8	970	1,302,172
1997	919	85	0	21,212,943	38,975	3,811	0	0	1,403	444,367
1998	14,229	481	3,790	1,623,287	26,199	5,247	0	0	512	566,875
Mean	3,435	480	985	5,022,714	35,278	2,897	31	2	640	286,201
Minimum	459	0	0	6,245	0	0	0	0	19	385
Maximum	14,229	1,356	3,790	21,212,943	79,348	5,247	279	10	1,403	1,302,172
SD	4,255	439	1,559	7,925,069	27,295	1,777	93	4	460	432,120
Total	30,914	4,324	8,867	45,204,425	317,506	26,076	279	19	5,756	2,575,807

0=Sampled, but none collected.

Fri Feb 08 09:49:58 MST 2002 ;Results; E Plant: seabrook.90.98 ; Units: annual.prod.forg Pathname: P:/Intake/Seabrook-Pilgrim/Science/scode/seabrook/tables.output.90.98.no.mussel/E.annual.prod.forg.seabrook.90.98.csv

Table G3-10: Annual Impingement (numbers of organisms) at Pilgrim, By Species, as Estimated by the Facility

Year	Alewife	American Eel	American Sand Lance	Atlantic Cod	Atlantic Herring	Atlantic Mackerel	Atlantic Menhaden	Atlantic Moonfish	Atlantic Silverside	Bay Anchovy	Black Ruff	Black Sea Bass	Blue Mussel	Blueback Herring
1974	4,542	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1975	NA	NA	NA	NA	NA	NA	NA	NA	702	NA	NA	NA	NA	NA
1976	NA	NA	NA	NA	45,065	NA	NA	NA	2,735	NA	NA	NA	NA	NA
1977	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1978	NA	NA	NA	NA	NA	NA	NA	NA	20,733	NA	NA	NA	NA	NA
1979	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1980	NA	NA	NA	NA	NA	NA	NA	NA	83,346	NA	NA	NA	NA	NA
1981	NA	NA	NA	NA	NA	NA	NA	NA	1,696	NA	NA	NA	NA	NA
1982	NA	NA	NA	NA	NA	NA	NA	NA	1,114	NA	NA	NA	NA	NA
1983	NA	NA	NA	NA	NA	NA	NA	NA	185	NA	NA	NA	NA	NA
1984	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1985	NA	NA	NA	NA	NA	NA	NA	NA	3,278	NA	NA	NA	NA	NA
1986	NA	NA	NA	NA	3,760	NA	NA	NA	NA	NA	NA	NA	NA	NA
1987	NA	NA	NA	NA	NA	NA	NA	NA	586	NA	NA	NA	NA	NA
1988	NA	NA	NA	NA	NA	NA	NA	NA	1,701	NA	NA	NA	NA	NA
1989	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1990	1,248	0	10	248	333	10	3,287	0	4,354	38	10	0	248	981
1991	419	0	52	315	41,419	0	1,975	0	4,806	52	0	35	629	542
1992	250	11	23	136	34	0	23	11	2,633	0	0	11	11	125
1993	676	0	0	390	130	0	52	0	9,365	0	0	0	0	325
1994	131	0	71	214	36	12	59	0	36,970	0	0	0	35	285
1995	26,972	0	0	288	144	0	1,052	14	15,857	0	0	58	0	1,254
1996	232	0	0	296	0	0	1,584	63	16,153	0	0	0	0	1,225
1997	289	0	0	58	19	0	1,078	0	5,814	19	0	0	39	347
1998	198	0	30	106	107	0	990	15	5,896	0	0	0	NA	122
1999	793	0	0	467	70	0	40,382	187	13,811	0	1	23	0	910
Mean	3,250	1	19	252	7,593	2	5,048	29	11,587	11	1	13	107	612
Minimum	131	0	0	58	0	0	23	0	185	0	0	0	0	122
Maximum	26,972	11	71	467	45,065	12	40,382	187	83,346	52	10	58	629	1,254
SD	7,969	3	25	128	16,703	5	12,456	59	19,184	19	3	20	211	442
Total	35,750	11	186	2,518	91,117	22	50,482	290	231,735	109	11	127	962	6,116

NA=Not sampled.

0=Sampled, but none collected.

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PATHNAME:P:/Intake/Seabrook-Pilgrim/Science/scode/pilgrim/tables.output.74.99.no.mussel/raw.losses.imp.pilgrim.74.99.csv

Table G3-10: Annual Impingement (numbers of organisms) at Pilgrim, By Species, as Estimated by the Facility (cont.)

Year	Blue-fish	Butter-fish	Cunner	Flying Gurnard	Fourbeard Rockling	Grubby	Hog-choker	Little Skate	Lump-fish	Northern Kingfish	Northern Pipefish	Northern Puffer	Orange Filefish	Pearl-side	Planehead Filefish	Pollock	Radiated Shanny
1974	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1975	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1976	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1977	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1978	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1979	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1980	NA	NA	1,683	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1981	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1982	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1983	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1984	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1985	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1986	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1987	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1988	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1989	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1990	0	1,601	210	0	0	562	0	0	105	0	29	57	38	0	0	38	10
1991	0	52	402	0	0	804	17	140	87	17	52	262	0	0	0	70	35
1992	0	0	34	0	0	488	0	91	136	0	23	23	0	0	11	11	34
1993	0	13	104	0	0	663	0	130	468	0	117	13	0	26	0	78	52
1994	0	48	83	0	0	1,164	0	48	202	0	190	0	0	0	0	12	154
1995	0	29	288	14	0	649	0	43	144	0	130	29	0	0	0	43	72
1996	0	21	211	0	0	1,204	0	21	169	0	127	0	0	0	0	0	21
1997	0	1,040	39	0	0	443	0	58	173	0	39	96	0	0	0	0	0
1998	15	30	76	0	15	259	0	76	289	0	0	0	0	0	0	0	46
1999	0	140	117	0	0	933	0	0	210	0	163	0	0	0	0	47	23
Mean	2	297	295	1	2	717	2	61	198	2	87	48	4	3	1	30	45
Minimum	0	0	34	0	0	259	0	0	87	0	0	0	0	0	0	0	0
Maximum	15	1,601	1,683	14	15	1,204	17	140	468	17	190	262	38	26	11	78	154
SD	5	557	474	4	5	309	5	49	111	5	66	81	12	8	3	29	44
Total	15	2,974	3,247	14	15	7,169	17	607	1,983	17	870	480	38	26	11	299	447

NA=Not sampled.
0=Sampled, but none collected.
Mon Feb 11 08:24:29 MST 2002 Raw.losses. IMPINGEMENT. Plant:pilgrim.74.99;
PATHNAME:P:/Intake/Seabrook-Pilgrim/Science/scode/pilgrim/tables.output.74.99.no.mussel/raw.losses.imp.pilgrim.74.99.csv

Table G3-10: Annual Impingement (numbers of organisms) at Pilgrim, By Species, as Estimated by the Facility (cont.)

Year	Rainbow Smelt	Red Hake	Rock Gunnel	Round Stad	Sculpin Spp.	Scup	Searobin	Silver Rag	Smooth Dogfish	Spiny Dogfish
1974	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1975	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1976	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1977	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1978	29,357	NA	NA	NA	NA	NA	NA	NA	NA	NA
1979	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1980	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1981	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1982	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1983	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1984	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1985	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1986	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1987	682	NA	NA	NA	NA	NA	NA	NA	NA	NA
1988	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1989	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1990	362	10	29	19	20	591	20	19	19	19
1991	717	157	105	0	17	315	122	0	17	17
1992	284	22	34	0	0	23	0	0	0	0
1993	9,560	221	117	0	13	13	65	0	0	13
1994	10,644	60	95	0	0	12	71	0	0	0
1995	2,335	114	72	0	0	0	72	0	0	0
1996	3,674	148	127	0	21	0	0	0	0	0
1997	1,579	250	0	0	0	0	58	0	0	0
1998	777	197	30	0	15	15	15	0	0	0
1999	1,446	606	23	0	23	0	140	0	0	0
Mean	5,118	178	63	2	11	97	56	2	4	5
Minimum	284	10	0	0	0	0	0	0	0	0
Maximum	29,357	606	127	19	23	591	140	19	19	19
SD	8,407	171	45	6	10	199	49	6	8	8
Total	61,417	1,785	632	19	109	969	563	19	36	49

NA=Not sampled.

0=Sampled, but none collected.

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PATHNAME:P:/Intake/Seabrook-Pilgrim/Science/scode/pilgrim/tables.output.74.99.no.mussel/raw.losses.imp.pilgrim.74.99.csv

Table G3-10: Annual Impingement (numbers of organisms) at Pilgrim, By Species, as Estimated by the Facility (cont.)

Year	Spot	Striped Bass	Striped Cusk Eel	Killifish Striped	Tautog	Threespine Stickleback	Unidentified	White Perch	Windowpane	Winter Flounder
1974	NA	NA	NA	NA	NA	NA	514	NA	NA	NA
1975	NA	NA	NA	NA	NA	NA	957	NA	NA	NA
1976	NA	NA	NA	NA	NA	NA	13,396	NA	NA	NA
1977	NA	NA	NA	NA	NA	NA	6,551	NA	NA	NA
1978	NA	NA	NA	NA	NA	NA	6,059	NA	NA	NA
1979	NA	NA	NA	NA	NA	NA	7,547	NA	NA	NA
1980	NA	NA	NA	NA	NA	NA	4,086	NA	NA	NA
1981	NA	NA	NA	NA	NA	NA	4,406	NA	NA	NA
1982	NA	NA	NA	NA	NA	NA	6,477	NA	NA	NA
1983	NA	NA	NA	NA	NA	NA	3,869	NA	NA	NA
1984	NA	NA	NA	NA	NA	NA	958	NA	NA	NA
1985	NA	NA	NA	NA	NA	NA	6,744	NA	NA	NA
1986	NA	NA	NA	NA	NA	NA	7,315	NA	NA	NA
1987	NA	NA	NA	NA	NA	NA	1,778	NA	NA	NA
1988	NA	NA	NA	NA	NA	NA	1,786	NA	NA	NA
1989	NA	NA	NA	NA	NA	NA	5,344	NA	NA	NA
1990	0	0	0	67	57	29	0	0	163	295
1991	0	0	0	139	315	35	0	52	227	1,171
1992	0	0	0	45	102	23	0	79	34	817
1993	13	0	13	39	299	78	0	0	143	1,184
1994	0	0	0	72	48	297	0	24	190	1,069
1995	0	0	0	58	72	159	0	14	158	1,326
1996	0	63	0	21	528	84	0	148	275	866
1997	0	0	0	0	154	39	0	39	96	770
1998	0	0	15	30	46	61	0	30	426	1,493
1999	0	0	0	187	210	23	0	163	653	1,400
Mean	1	6	3	66	183	83	2,992	55	236	1,039
Minimum	0	0	0	0	46	23	0	0	34	295
Maximum	13	63	15	187	528	297	13,396	163	653	1,493
SD	4	20	6	57	157	86	3,535	58	181	360
Total	13	63	28	658	1,831	828	77,787	549	2,365	10,391

NA=Not sampled.

0=Sampled, but none collected.

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PATHNAME:P:/Intake/Seabrook-Pilgrim/Science/scode/pilgrim/tables.output.74.99.no.mussel/raw.losses.imp.pilgrim.74.99.csv

Table G3-11: Annual Impingement at Pilgrim, By Species, Expressed as Age 1 Equivalents

Year	Alewife	American Sand Lance	Atlantic Cod	Atlantic Herring	Atlantic Mackerel	Atlantic Menhaden	Atlantic Silverside	Bay Anchovy	Blueback Herring	Bluefish	Butterfish	Cunner
1974	6,070	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1975	NA	NA	NA	NA	NA	NA	1,263	NA	NA	NA	NA	NA
1976	NA	NA	NA	52,439	NA	NA	NA	NA	NA	NA	NA	NA
1977	NA	NA	NA	NA	NA	NA	4,920	NA	NA	NA	NA	NA
1978	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1979	NA	NA	NA	NA	NA	NA	37,294	NA	NA	NA	NA	NA
1980	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	2,345
1981	NA	NA	NA	NA	NA	NA	149,922	NA	NA	NA	NA	NA
1982	NA	NA	NA	NA	NA	NA	3,051	NA	NA	NA	NA	NA
1983	NA	NA	NA	NA	NA	NA	2,004	NA	NA	NA	NA	NA
1984	NA	NA	NA	NA	NA	NA	333	NA	NA	NA	NA	NA
1985	NA	NA	NA	NA	NA	NA	5,896	NA	NA	NA	NA	NA
1986	NA	NA	NA	4,375	NA	NA	NA	NA	NA	NA	NA	NA
1987	NA	NA	NA	NA	NA	NA	1,054	NA	NA	NA	NA	NA
1988	NA	NA	NA	NA	NA	NA	3,060	NA	NA	NA	NA	NA
1989	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1990	1,668	15	297	387	13	4,014	7,832	63	1,127	0	2,146	293
1991	560	76	377	48,196	0	2,412	8,645	87	623	0	70	560
1992	334	34	163	40	0	28	4,736	0	144	0	0	47
1993	903	0	467	151	0	64	16,846	0	373	0	17	145
1994	175	104	256	42	15	72	66,501	0	327	0	64	116
1995	36,045	0	345	168	0	1,285	28,523	0	1,441	0	39	401
1996	310	0	354	0	0	1,935	29,056	0	1,407	0	28	294
1997	386	0	69	22	0	1,317	10,458	32	399	0	1,394	54
1998	265	44	127	125	0	1,209	10,606	0	140	19	40	106
1999	1,060	0	559	81	0	49,318	24,843	0	1,045	0	188	163
Mean	4,343	27	301	8,836	3	6,165	20,842	18	703	2	399	411
Minimum	175	0	69	0	0	28	333	0	140	0	0	47
Maximum	36,045	104	559	52,439	15	49,318	149,922	87	1,441	19	2,146	2,345
SD	10,649	37	153	19,436	6	15,212	34,508	32	507	6	746	660
Total	47,775	272	3,015	106,027	28	61,653	416,842	182	7,027	19	3,987	4,524

Note: Impingement losses expressed as age 1 equivalents are larger than raw losses (the actual number of organisms impinged). This is because the ages of impinged individuals are assumed to be distributed across the interval between the start of year 1 and the start of year 2, and then the losses are normalized back to the start of year 1 by accounting for mortality during this interval (for details, see description of S*j in Chapter A2, Equation 4 and Equation 5). This type of adjustment is applied to all raw loss records, but the effect is not readily apparent among entrainment losses because the majority of entrained fish are younger than age 1.
NA=Not sampled.
0=Sampled, but none collected.
Mon Feb 11 10:06:07 MST 2002 ;Results; I Plant: pilgrim.74.99 ; Units: equivalent.sums,Pathname: P:/Intake/Seabrook-Pilgrim/Science/scode/pilgrim/tables.output.74.99.no.mussel/I.equivalent.sums.pilgrim.74.99.csv

Table G3-11: Annual Impingement at Pilgrim, By Species, Expressed as Age 1 Equivalents (cont.)

Year	Fourbeard Rockling	Grubby	Hogchoker	Little Skate	Lumpfish	Northern Pipefish	Pollock	Radiated Shanny	Rainbow Smelt	Red Hake	Rock Gunnel	Sculpin Spp.	Scup
1974	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1975	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1976	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1977	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1978	NA	NA	NA	NA	NA	NA	NA	NA	39,747	NA	NA	NA	NA
1979	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1980	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1981	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1982	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1983	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1984	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1985	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1986	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1987	NA	NA	NA	NA	NA	NA	NA	NA	923	NA	NA	NA	NA
1988	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1989	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1990	0	689	0	0	115	39	42	12	490	13	35	25	696
1991	0	986	19	180	95	71	77	43	971	201	128	21	371
1992	0	598	0	117	149	31	12	41	385	28	41	0	27
1993	0	813	0	167	512	159	86	63	12,943	283	142	16	15
1994	0	1,427	0	62	221	258	13	187	14,411	77	116	0	14
1995	0	796	0	55	158	177	47	88	3,161	146	88	0	0
1996	0	1,476	0	27	185	173	0	26	4,974	189	154	26	0
1997	0	543	0	74	189	53	0	0	2,138	320	0	0	0
1998	19	318	0	97	316	0	0	56	1,052	252	36	18	18
1999	0	1,144	0	0	230	221	52	28	1,958	776	28	28	0
Mean	2	879	2	78	217	118	33	54	6,929	229	77	13	114
Minimum	0	318	0	0	95	0	0	0	385	13	0	0	0
Maximum	19	1,476	19	180	512	258	86	187	39,747	776	154	28	696
SD	6	379	6	63	121	90	32	53	11,383	219	55	12	234
Total	19	8,789	19	778	2,171	1,182	329	544	83,153	2,285	769	134	1,140

Note: Impingement losses expressed as age 1 equivalents are larger than raw losses (the actual number of organisms impinged). This is because the ages of impinged individuals are assumed to be distributed across the interval between the start of year 1 and the start f year 2, and then the losses are normalized back to the start of year 1 by accounting for mortality during this interval (for details, see description of S*j in Chapter A2, Equation 4 and Equation 5). This type of adjustment is applied to all raw loss records, but the effect is not readily apparent among entrainment losses because the majority of entrained fish are younger than age 1.

NA=Not sampled.

0=Sampled, but none collected.

Mon Feb 11 10:06:07 MST 2002 ;Results; I Plant: pilgrim.74.99 ; Units: equivalent.sums Pathname: P:/Intake/Seabrook-Pilgrim/Science/scode/pilgrim/tables.output.74.99.no.mussel/I.equivalent.sums.pilgrim.74.99

Pilgrim/Science/scode/pilgrim/tables.output.74.99.no.mussel/I.equivalent.sums.pilgrim.74.99.csv

Table G3-11: Annual Impingement at Pilgrim, By Species, Expressed as Age 1 Equivalents (cont.)

Year	Searobin	Striped Bass	Striped Killifish	Tautog	Threespine Stickleback	White Perch	Windowpane	Winter Flounder
1974	NA	NA	NA	NA	NA	NA	NA	NA
1975	NA	NA	NA	NA	NA	NA	NA	NA
1976	NA	NA	NA	NA	NA	NA	NA	NA
1977	NA	NA	NA	NA	NA	NA	NA	NA
1978	NA	NA	NA	NA	NA	NA	NA	NA
1979	NA	NA	NA	NA	NA	NA	NA	NA
1980	NA	NA	NA	NA	NA	NA	NA	NA
1981	NA	NA	NA	NA	NA	NA	NA	NA
1982	NA	NA	NA	NA	NA	NA	NA	NA
1983	NA	NA	NA	NA	NA	NA	NA	NA
1984	NA	NA	NA	NA	NA	NA	NA	NA
1985	NA	NA	NA	NA	NA	NA	NA	NA
1986	NA	NA	NA	NA	NA	NA	NA	NA
1987	NA	NA	NA	NA	NA	NA	NA	NA
1988	NA	NA	NA	NA	NA	NA	NA	NA
1989	NA	NA	NA	NA	NA	NA	NA	NA
1990	25	0	92	63	41	0	196	325
1991	150	0	190	346	50	69	272	1,289
1992	0	0	62	112	33	105	41	899
1993	80	0	53	328	111	0	172	1,303
1994	87	0	99	53	422	32	228	1,177
1995	89	0	79	79	226	19	190	1,460
1996	0	94	29	579	119	197	330	953
1997	71	0	0	169	55	52	115	848
1998	18	0	41	50	87	40	511	1,643
1999	172	0	256	230	33	217	784	1,541
Mean	69	9	90	201	118	73	284	1,144
Minimum	0	0	0	50	33	0	41	325
Maximum	172	94	256	579	422	217	784	1,643
SD	60	30	78	173	122	78	217	396
Total	693	94	901	2,009	1,177	732	2,839	11,438

Note: Impingement losses expressed as age 1 equivalents are larger than raw losses (the actual number of organisms impinged). This is because the ages of impinged individuals are assumed to be distributed across the interval between the start of year 1 and the start of year 2, and then the losses are normalized back to the start of year 1 by accounting for mortality during this interval (for details, see description of S*j in Chapter A2, Equation 4 and Equation 5). This type of adjustment is applied to all raw loss records, but the effect is not readily apparent among entrainment losses because the majority of entrained fish are younger than age 1.
NA=Not sampled.
0=Sampled, but none collected.
Mon Feb 11 10:06:07 MST 2002 ;Results; I Plant: pilgrim.74.99 ; Units: equivalent.sums Pathname: P:/Intake/Seabrook-Pilgrim/Science/scode/pilgrim/tables.output.74.99.no.mussel/I.equivalent.sums.pilgrim.74.99.csv

Table 63-12: Annual Impingement of Fishery Species at Pilgrim Expressed as Yield Lost to Fisheries (in pounds)

Year	Alewife	Atlantic Cod	Atlantic Herring	Atlantic Mackerel	Atlantic Menhaden	Atlantic Silverside	Blueback Herring	Bluefish	Butterfish	Cunner
1974	31	NA	NA	NA	NA	NA	NA	NA	NA	NA
1975	NA	NA	NA	NA	NA	0	NA	NA	NA	NA
1976	NA	NA	7,268	NA	NA	NA	NA	NA	NA	NA
1977	NA	NA	NA	NA	NA	2	NA	NA	NA	NA
1978	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1979	NA	NA	NA	NA	NA	14	NA	NA	NA	NA
1980	NA	NA	NA	NA	NA	NA	NA	NA	NA	11
1981	NA	NA	NA	NA	NA	58	NA	NA	NA	NA
1982	NA	NA	NA	NA	NA	1	NA	NA	NA	NA
1983	NA	NA	NA	NA	NA	1	NA	NA	NA	NA
1984	NA	NA	NA	NA	NA	0	NA	NA	NA	NA
1985	NA	NA	NA	NA	NA	2	NA	NA	NA	NA
1986	NA	NA	606	NA	NA	NA	NA	NA	NA	NA
1987	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1988	NA	NA	NA	NA	NA	0	NA	NA	NA	NA
1989	NA	NA	NA	NA	NA	1	NA	NA	NA	NA
1990	8	97	54	2	1,375	3	9	0	104	1
1991	3	123	6,680	0	826	3	5	0	3	3
1992	2	53	5	0	10	2	1	0	0	0
1993	5	153	21	0	22	7	3	0	1	1
1994	1	84	6	2	25	26	2	0	3	1
1995	182	113	23	0	440	11	11	0	2	2
1996	2	116	0	0	662	11	11	0	1	1
1997	2	23	3	0	451	4	3	0	67	0
1998	1	42	17	0	414	4	1	11	2	0
1999	5	183	11	0	16,888	10	8	0	9	1
Mean	22	99	1,225	0	2,111	8	5	1	19	2
Minimum	1	23	0	0	10	0	1	0	0	0
Maximum	182	183	7,268	2	16,888	58	11	11	104	11
SD	54	50	2,694	1	5,209	13	4	3	36	3
Total	241	987	14,695	4	21,112	162	53	11	193	20

NA=Not sampled.

0=Sampled, but none collected.

Mon Feb 11 10:06:21 MST 2002 ;Results; I Plant: pilgrim.74.99 ; Units: yield Pathname: P:/Intake/Seabrook-Pilgrim/Science/scode/pilgrim/tables.output.74.99.no.mussel/I.yield.pilgrim.74.99.csv

Table G3-12: Annual Impingement of Fishery Species at Pilgrim Expressed as Yield Lost to Fisheries (in pounds) (cont.)

Year	Little Skate	Pollock	Rainbow Smelt	Red Hake	Scup	Searobin	Striped Bass	Tautog	Windowpane	Winter Flounder
1974	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1975	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1976	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1977	NA	NA	297	NA	NA	NA	NA	NA	NA	NA
1978	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1979	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1980	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1981	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1982	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1983	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1984	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1985	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1986	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1987	NA	NA	7	NA	NA	NA	NA	NA	NA	NA
1988	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1989	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1990	0	61	4	2	131	1	0	69	14	102
1991	37	113	7	36	70	7	0	384	20	406
1992	24	18	3	5	5	0	0	124	3	283
1993	34	126	97	50	3	4	0	364	13	411
1994	13	19	108	14	3	4	0	58	17	371
1995	11	69	24	26	0	4	0	88	14	460
1996	6	0	37	34	0	0	131	643	24	300
1997	15	0	16	57	0	4	0	188	8	267
1998	20	0	8	45	3	1	0	56	38	518
1999	0	76	15	138	0	9	0	256	58	486
Mean	16	48	52	41	21	3	13	223	21	361
Minimum	0	0	3	2	0	0	0	56	3	102
Maximum	37	126	297	138	131	9	131	643	58	518
SD	13	48	85	39	44	3	41	192	16	125
Total	161	483	622	407	215	34	131	2,230	209	3,605

NA=Not sampled.

0=Sampled, but none collected.

Mon Feb 11 10:06:21 MST 2002 ; Results; I Plant: pilgrim.74.99 ; Units: yield Pathname: P:/Intake/Seabrook-Pilgrim/Science/scode/pilgrim/tables.output.74.99.no.mussel/I.yield.pilgrim.74.99.csv

Table G3-13: Annual Impingement at Pilgrim, By Species, Expressed as Production Foregone (in pounds)

Year	Alewife	American Sand Lance	Atlantic Cod	Atlantic Herring	Atlantic Mackerel	Atlantic Menhaden	Atlantic Silverside	Blueback Herring	Blue-fish	Butter-fish	Cunner	Grubby	Little Skate	Lump-fish
1974	190	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1975	NA	NA	NA	NA	NA	NA	0	NA	NA	NA	NA	NA	NA	NA
1976	NA	NA	NA	4,094	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1977	NA	NA	NA	NA	NA	NA	2	NA	NA	NA	NA	NA	NA	NA
1978	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1979	NA	NA	NA	NA	NA	NA	13	NA	NA	NA	NA	NA	NA	NA
1980	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	13	NA	NA	NA
1981	NA	NA	NA	NA	NA	NA	52	NA	NA	NA	NA	NA	NA	NA
1982	NA	NA	NA	NA	NA	NA	1	NA	NA	NA	NA	NA	NA	NA
1983	NA	NA	NA	NA	NA	NA	1	NA	NA	NA	NA	NA	NA	NA
1984	NA	NA	NA	NA	NA	NA	0	NA	NA	NA	NA	NA	NA	NA
1985	NA	NA	NA	NA	NA	NA	2	NA	NA	NA	NA	NA	NA	NA
1986	NA	NA	NA	342	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1987	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1988	NA	NA	NA	NA	NA	NA	0	NA	NA	NA	NA	NA	NA	NA
1989	NA	NA	NA	NA	NA	NA	1	NA	NA	NA	NA	NA	NA	NA
1990	52	0	34	30	1	628	3	52	0	50	2	42	0	4
1991	18	0	43	3,762	0	377	3	29	0	2	3	60	17	3
1992	10	0	19	3	0	4	2	7	0	0	0	36	11	5
1993	28	0	53	12	0	10	6	17	0	0	1	49	16	17
1994	5	1	29	3	1	11	23	15	0	2	1	87	6	7
1995	1,128	0	39	13	0	201	10	66	0	1	2	48	5	5
1996	10	0	41	0	0	303	10	64	0	1	2	90	3	6
1997	12	0	8	2	0	206	4	18	0	33	0	33	7	6
1998	8	0	15	10	0	189	4	6	2	1	1	19	9	10
1999	33	0	64	6	0	7,715	9	48	0	4	1	70	0	7
Mean	136	0	34	690	0	964	7	32	0	9	2	53	7	7
Minimum	5	0	8	0	0	4	0	6	0	0	0	19	0	3
Maximum	1,128	1	64	4,094	1	7,715	52	66	2	50	13	90	17	17
SD	333	0	17	1,517	1	2,380	12	23	1	17	4	23	6	4
Total	1,495	1	345	8,277	3	9,644	144	322	2	93	25	535	75	70

NA=Not sampled.

0=Sampled, but none collected.

Mon Feb 11 10:06:14 MST 2002 ;Results; I Plant: pilgrim.74.99 ; Units: annual.prod.forg Pathname: P:/Intake/Seabrook-Pilgrim/Science/scode/pilgrim/tables.output.74.99.no.mussel/I.annual.prod.forg.pilgrim.74.99.csv

Table 63-13: Annual Impingement at Pilgrim, By Species, Expressed as Production Foregone (in pounds) (cont.)

Year	Pollock	Rainbow Smelt	Red Hake	Rock Gunnel	Sculpin Spp.	Scup	Searobin	Striped Bass	Striped Killifish	Tautog	White Perch	Windowpane	Winter Flounder
1974	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1975	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1976	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1977	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1978	NA	1,219	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1979	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1980	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1981	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1982	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1983	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1984	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1985	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1986	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1987	NA	28	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1988	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1989	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1990	20	15	2	0	1	67	2	0	1	8	0	3	39
1991	36	30	27	1	1	36	11	0	1	43	0	5	156
1992	6	12	4	0	0	3	0	0	0	14	0	1	109
1993	40	397	39	1	1	1	6	0	0	41	0	3	158
1994	6	442	10	1	0	1	7	0	1	7	0	4	142
1995	22	97	20	0	0	0	7	0	0	10	0	3	176
1996	0	153	26	1	2	0	0	27	0	72	1	6	115
1997	0	66	44	0	0	0	5	0	0	21	0	2	102
1998	0	32	34	0	1	2	1	0	0	6	0	9	199
1999	24	60	106	0	2	0	13	0	2	29	1	14	186
Mean	15	212	31	0	1	11	5	3	1	25	0	5	138
Minimum	0	12	2	0	0	0	0	0	0	6	0	1	39
Maximum	40	1,219	106	1	2	67	13	27	2	72	1	14	199
SD	15	349	30	0	1	23	4	8	0	21	0	4	48
Total	154	2,549	312	3	8	111	52	27	6	249	2	51	1,383

NA=Not sampled.

0=Sampled, but none collected.

Mon Feb 11 10:06:14 MST 2002 ;Results; I Plant: pilgrim.74.99 ; Units: annual.prod.forg Pathname: P:/Intake/Seabrook-Pilgrim/Science/scode/pilgrim/tables.output.74.99.no.mussel/I.annual.prod.forg.pilgrim.74.99.csv

Table G3-14: Annual Entrainment (numbers of organisms) at Pilgrim, By Species, as Estimated by the Facility.

Year	Alewife	American Plaice	American Sand Lance	Atlantic Cod	Atlantic Herring	Atlantic Mackerel	Atlantic Menhaden	Atlantic Silverside	Blue Mussel	Cunner
1974	957,330	NA	NA	NA	NA	NA	76,436,500	323,810	2,208,700,000,000	1,177,600,000
1975	0	NA	NA	NA	NA	NA	7,280,500	1,546,620	19,122,000,000,000	1,177,600,000
1976	12,976	NA	NA	NA	NA	NA	21,696,300	2,436,575	2,891,200,000,000	1,177,600,000
1977	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1978	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1979	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1980	NA	NA	NA	21,839,372	1,068,466	103,892,540	28,529,199	NA	NA	3,378,883,316
1981	NA	NA	NA	13,793,664	2,471,492	504,095,387	43,549,879	NA	NA	7,152,617,480
1982	NA	NA	NA	2,805,705	732,857	117,623,074	366,937,320	NA	NA	2,020,915,711
1983	NA	NA	NA	9,491,864	5,880,315	189,950,294	2,096,770	NA	NA	5,937,818,325
1984	NA	NA	NA	12,313,633	468,840	22,564,934	4,751,607	NA	NA	1,767,970,898
1985	NA	NA	NA	6,512,593	1,580,435	1,913,359,781	50,322,124	NA	NA	2,061,768,342
1986	NA	NA	NA	3,824,754	1,811,101	277,821,586	24,767,656	NA	NA	1,520,567,067
1987	NA	NA	NA	5,745,861	5,142,045	71,437,855	1,872,216	NA	NA	4,506,374,514
1988	NA	NA	NA	3,001,273	639,089	2,667,010,057	11,987,628	NA	NA	1,546,465,819
1989	NA	NA	NA	3,515,162	911,487	4,739,478,407	15,623,972	NA	NA	4,521,604,135
1990	NA	2,386,979	60,886,295	3,972,827	2,079,483	2,318,043,737	10,320,759	NA	NA	1,508,146,909
1991	NA	3,434,141	23,485,288	3,908,395	1,280,273	545,771,347	6,256,434	NA	NA	691,736,018
1992	NA	12,355,715	108,323,789	3,289,386	3,970,208	385,697,157	1,510,414	NA	NA	2,177,452,952
1993	NA	54,863,855	46,668,316	1,715,237	2,098,952	1,809,704,207	959,648,788	NA	NA	3,250,567,317
1994	NA	6,286,118	458,829,894	5,023,831	16,351,765	524,336,520	12,583,586	NA	NA	1,568,239,739
1995	NA	5,219,224	54,688,357	3,151,964	43,247,883	1,965,298,971	15,700,367	NA	NA	4,163,622,052
1996	NA	3,931,000	340,701,000	10,912,177	9,265,826	1,578,317,735	13,522,139	NA	NA	2,824,542,922
1997	NA	4,809,142	106,911,770	2,901,829	24,445,056	342,747,452	97,182,867	NA	NA	1,817,924,713
1998	NA	8,055,050	41,715,642	5,706,922	4,026,783	586,639,654	78,011,253	NA	NA	4,711,882,277
1999	NA	NA	NA	2,397,019	11,379,446	35,506,522	33,719,962	NA	NA	1,773,984,349
Mean	323,435	11,260,136	138,023,372	6,291,173	6,942,590	1,034,964,861	81,926,445	1,435,668	8,073,966,666,670	2,714,603,689
Minimum	0	2,386,979	23,485,288	1,715,237	468,840	22,564,934	1,510,414	323,810	2,208,700,000,000	691,736,018
Maximum	957,330	54,863,855	458,829,894	21,839,372	43,247,883	4,739,478,407	959,648,788	2,436,575	19,122,000,000,000	7,152,617,480
SD	549,007	16,618,143	153,899,234	5,039,143	10,525,822	1,222,538,368	205,740,114	1,060,743	9,573,961,142,770	1,704,407,272
Total	970,306	101,341,224	1,242,210,351	125,823,468	138,851,802	20,699,297,217	1,884,308,240	4,307,005	24,221,900,000,000	62,435,884,855

NA=Not sampled.

0=Sampled, but none collected.

Mon Feb 11 08:24:30 MST 2002 Raw.losses. ENTRAINMENT; Plant:pilgrim.74.99;

PATHNAME:P:/Intake/Seabrook-Pilgrim/Science/scode/pilgrim/tables.output.74.99.no.mussel/raw.losses.ent.pilgrim.74.99.csv

Table G3-14: Annual Entrainment (numbers of organisms) at Pilgrim, By Species, as Estimated by the Facility (cont.)

Year	Fourbeard Rockling	Lumpfish	Pollock	Radiated Shanny	Rainbow Smelt	Red Hake	Rock Gunnel	Sculpin Spp.	Searobin	Tautog	Windowpane	Winter Flounder
1974	NA	NA	104,972,000	NA	30,105,000	NA	NA	NA	NA	NA	NA	225,000,000
1975	NA	NA	2,144,710	NA	145,400	NA	NA	NA	NA	NA	NA	52,280,000
1976	NA	NA	21,137,710	NA	87,242	NA	NA	NA	NA	NA	NA	33,725,000
1977	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1978	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1979	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1980	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	28,726,407
1981	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	29,856,493
1982	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	21,439,774
1983	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	11,998,509
1984	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	8,334,474
1985	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	11,508,028
1986	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	15,221,824
1987	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	3,526,013
1988	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	19,243,313
1989	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	9,687,852
1990	161,001,461	7,829,710	NA	16,056,794	NA	NA	12,268,408	26,003,576	1,725,190	8,720,243	60,919,472	8,678,807
1991	141,180,985	7,257,673	NA	14,010,361	NA	NA	37,694,011	44,379,996	2,591,103	3,849,374	50,098,443	12,605,283
1992	126,361,457	2,222,841	NA	13,014,884	NA	NA	30,028,438	7,409,762	1,389,931	3,142,186	61,663,329	8,811,456
1993	60,326,651	9,340,124	NA	19,514,380	NA	NA	7,455,162	38,339,208	3,466,096	4,367,106	152,988,400	10,160,019
1994	60,933,441	10,595,602	NA	13,330,063	NA	23,254,273	62,079,785	34,041,077	1,080,077	1,321,569	73,781,569	20,701,312
1995	33,524,219	7,828,837	NA	16,190,247	NA	4,789,498	13,281,171	31,147,018	2,522,305	2,376,502	42,663,536	13,655,283
1996	29,396,000	4,305,000	NA	32,569,000	NA	14,447,000	33,497,000	50,775,000	1,213,000	5,319,000	99,739,000	18,648,291
1997	95,461,605	8,196,313	NA	12,958,397	NA	50,281,351	97,510,007	88,316,035	2,824,213	9,763,040	94,240,177	55,373,718
1998	140,083,704	830,815	NA	35,957,121	NA	62,604,501	15,175,912	47,161,167	918,471	28,756,809	115,833,081	86,846,061
1999	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	4,680,713
Mean	94,252,169	6,489,657	42,751,473	19,289,027	10,112,547	31,075,325	34,332,210	40,841,427	1,970,043	7,512,870	83,547,445	30,900,375
Minimum	29,396,000	830,815	2,144,710	12,958,397	87,242	4,789,498	7,455,162	7,409,762	918,471	1,321,569	42,663,536	3,526,013
Maximum	161,001,461	10,595,602	104,972,000	35,957,121	30,105,000	62,604,501	97,510,007	88,316,035	3,466,096	28,756,809	152,988,400	225,000,000
SD	49,932,536	3,299,177	54,714,979	8,782,788	17,313,996	24,451,867	29,178,718	22,049,094	903,184	8,439,294	35,562,535	46,599,404
Total	848,269,523	58,406,915	128,254,420	173,601,247	30,337,642	155,376,623	308,989,894	367,572,839	17,730,386	67,615,829	751,927,007	710,708,630

NA=Not sampled.
0=Sampled, but none collected.
Mon Feb 11 08:24:30 MST 2002 Raw.losses. ENTRAINMENT; Plant:pilgrim.74.99;
PATHNAME:P:/Intake/Seabrook-Pilgrim/Science/scode/pilgrim/tables.output.74.99.no.mussel/raw.losses.ent.pilgrim.74.99.csv

Table G3-15: Annual Entrainment at Pilgrim, By Species, Expressed as Age 1 Equivalents

Year	American Plaice	American Sand Lance	Atlantic Cod	Atlantic Herring	Atlantic Mackerel	Atlantic Menhaden	Atlantic Silverside	Cunner	Fourbeard Rockling	Lumpfish	Pollock
1974	NA	NA	NA	NA	NA	28,754	1,416	724,630	NA	NA	1,201
1975	NA	NA	NA	NA	NA	2,383	3,578	724,630	NA	NA	70
1976	NA	NA	NA	NA	NA	5,842	10,265	724,630	NA	NA	206
1977	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1978	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1979	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1980	NA	NA	3,758	3,115	1,459	5,305	NA	1,314,956	NA	NA	NA
1981	NA	NA	5,292	7,206	16,812	15,454	NA	4,660,735	NA	NA	NA
1982	NA	NA	567	2,137	925	16,201	NA	421,665	NA	NA	NA
1983	NA	NA	500	17,145	2,695	506	NA	1,313,416	NA	NA	NA
1984	NA	NA	1,583	1,367	98	202	NA	323,971	NA	NA	NA
1985	NA	NA	3,463	4,608	10,130	5,256	NA	603,370	NA	NA	NA
1986	NA	NA	2,474	5,281	3,844	2,292	NA	430,335	NA	NA	NA
1987	NA	NA	387	14,993	310	609	NA	1,046,996	NA	NA	NA
1988	NA	NA	644	1,863	11,351	1,430	NA	320,441	NA	NA	NA
1989	NA	NA	340	2,658	22,903	2,161	NA	1,116,427	NA	NA	NA
1990	47	1,815,806	3,707	6,063	9,942	1,546	NA	1,279,249	583,611	1,303	NA
1991	67	700,399	627	3,733	5,321	439	NA	222,102	714,005	1,208	NA
1992	242	3,230,530	1,149	11,576	1,990	444	NA	406,666	438,229	370	NA
1993	1,076	1,391,785	1,067	6,120	7,978	44,749	NA	672,052	211,060	1,554	NA
1994	123	13,683,639	4,511	47,678	2,358	1,336	NA	339,643	301,560	1,763	NA
1995	102	1,630,966	1,455	126,100	17,325	4,883	NA	1,022,608	119,501	1,303	NA
1996	77	10,160,693	5,696	27,017	9,882	3,514	NA	608,403	266,426	716	NA
1997	94	3,188,419	2,608	71,276	2,622	20,516	NA	909,960	393,940	1,364	NA
1998	158	1,244,082	1,809	11,741	5,062	14,609	NA	3,014,964	672,366	138	NA
1999	NA	NA	1,120	33,180	171	7,991	NA	648,654	NA	NA	NA
Mean	221	4,116,258	2,138	20,243	6,659	8,105	5,087	993,500	411,189	1,080	492
Minimum	47	700,399	340	1,367	98	202	1,416	222,102	119,501	138	70
Maximum	1,076	13,683,639	5,696	126,100	22,903	44,749	10,265	4,660,735	714,005	1,763	1,201
SD	326	4,589,722	1,708	30,691	6,520	11,010	4,613	988,573	208,799	549	617
Total	1,988	37,046,318	42,758	404,856	133,179	186,422	15,260	22,850,503	3,700,698	9,718	1,477

NA=Not sampled.

0=Sampled, but none collected.

Mon Feb 11 10:06:01 MST 2002 ;Results; E Plant: pilgrim.74.99 ; Units: equivalent.sums Pathname: P:/Intake/Seabrook-

Pilgrim/Science/scode/pilgrim/tables.output.74.99.no.mussel/E.equivalent.sums.pilgrim.74.99.csv

Table G3-15: Annual Entrainment at Pilgrim, By Species, Expressed as Age 1 Equivalents (cont.)

Year	Radiated Shanny	Rainbow Smelt	Red Hake	Rock Gunnel	Sculpin Spp.	Searobin	Tautog	Windowpane	Winter Flounder
1974	NA	3,938,972	NA	NA	NA	NA	NA	NA	731,769
1975	NA	19,024	NA	NA	NA	NA	NA	NA	170,030
1976	NA	11,415	NA	NA	NA	NA	NA	NA	109,684
1977	NA	NA	NA	NA	NA	NA	NA	NA	NA
1978	NA	NA	NA	NA	NA	NA	NA	NA	NA
1979	NA	NA	NA	NA	NA	NA	NA	NA	NA
1980	NA	NA	NA	NA	NA	NA	NA	NA	126,854
1981	NA	NA	NA	NA	NA	NA	NA	NA	110,909
1982	NA	NA	NA	NA	NA	NA	NA	NA	182,727
1983	NA	NA	NA	NA	NA	NA	NA	NA	110,701
1984	NA	NA	NA	NA	NA	NA	NA	NA	128,815
1985	NA	NA	NA	NA	NA	NA	NA	NA	98,949
1986	NA	NA	NA	NA	NA	NA	NA	NA	75,135
1987	NA	NA	NA	NA	NA	NA	NA	NA	30,164
1988	NA	NA	NA	NA	NA	NA	NA	NA	207,002
1989	NA	NA	NA	NA	NA	NA	NA	NA	47,147
1990	1,368,852	NA	NA	1,737,690	467,819	3,238	1,016	12,584	72,462
1991	1,194,392	NA	NA	5,338,958	798,421	4,864	449	10,349	72,170
1992	1,109,527	NA	NA	4,253,211	133,306	2,609	366	12,737	73,003
1993	1,663,613	NA	NA	1,055,945	689,744	6,506	509	31,602	70,569
1994	1,136,396	NA	1,156	8,792,945	612,418	2,027	154	15,241	163,886
1995	1,380,229	NA	238	1,881,138	560,352	4,735	277	8,813	136,714
1996	2,776,528	NA	718	4,744,496	913,471	2,277	620	20,602	236,922
1997	1,104,711	NA	2,500	13,811,262	1,588,855	5,301	1,138	19,467	659,882
1998	3,065,367	NA	3,112	2,149,508	848,456	1,724	3,351	23,927	1,166,820
1999	NA	NA	NA	NA	NA	NA	NA	NA	37,806
Mean	1,644,402	1,323,137	1,545	4,862,795	734,760	3,698	875	17,258	209,571
Minimum	1,104,711	11,415	238	1,055,945	133,306	1,724	154	8,813	30,164
Maximum	3,065,367	3,938,972	3,112	13,811,262	1,588,855	6,506	3,351	31,602	1,166,820
SD	748,738	2,265,383	1,216	4,132,857	396,676	1,695	983	7,346	272,956
Total	14,799,615	3,969,411	7,724	43,765,153	6,612,841	33,282	7,879	155,321	4,820,123

NA=Not sampled.

0=Sampled, but none collected.

Mon Feb 11 10:06:01 MST 2002 ;Results; E Plant: pilgrim.74.99 ; Units: equivalent.sums Pathname: P:/Intake/Seabrook-Pilgrim/Science/scode/pilgrim/tables.output.74.99.no.mussel/E.equivalent.sums.pilgrim.74.99.csv

Table 63-16: Annual Entrainment of Fishery Species at Pilgrim Expressed as Yield Lost to Fisheries (in pounds)

Year	Atlantic Cod	Atlantic Mackerel	Cunner	Atlantic Herring	Atlantic Menhaden	American Plaice	Pollock	Rainbow Smelt	Red Hake	Sea-robin	Atlantic Silverside	Tautog	Window-pane	Winter Flounder
1974	NA	NA	3,268	NA	9,846	NA	1,763	29,473	NA	NA	1	NA	NA	230,673
1975	NA	NA	3,268	NA	816	NA	103	142	NA	NA	1	NA	NA	53,598
1976	NA	NA	3,268	NA	2,001	NA	302	85	NA	NA	4	NA	NA	34,575
1977	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1978	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1979	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1980	1,230	202	5,930	432	1,817	NA	NA	NA	NA	NA	NA	NA	NA	39,988
1981	1,732	2,325	21,020	999	5,292	NA	NA	NA	NA	NA	NA	NA	NA	34,962
1982	186	128	1,902	296	5,548	NA	NA	NA	NA	NA	NA	NA	NA	57,601
1983	164	373	5,923	2,376	173	NA	NA	NA	NA	NA	NA	NA	NA	34,896
1984	518	14	1,461	189	69	NA	NA	NA	NA	NA	NA	NA	NA	40,606
1985	1,134	1,401	2,721	639	1,800	NA	NA	NA	NA	NA	NA	NA	NA	31,191
1986	810	532	1,941	732	785	NA	NA	NA	NA	NA	NA	NA	NA	23,685
1987	127	43	4,722	2,078	209	NA	NA	NA	NA	NA	NA	NA	NA	9,509
1988	211	1,570	1,445	258	490	NA	NA	NA	NA	NA	NA	NA	NA	65,253
1989	111	3,167	5,035	368	740	NA	NA	NA	NA	NA	NA	NA	NA	14,862
1990	1,214	1,375	5,769	840	529	5	NA	NA	NA	161	NA	1,128	928	22,842
1991	205	736	1,002	517	150	8	NA	NA	NA	242	NA	498	763	22,750
1992	376	275	1,834	1,604	152	28	NA	NA	NA	130	NA	407	939	23,013
1993	349	1,103	3,031	848	15,323	123	NA	NA	NA	324	NA	565	2,330	22,245
1994	1,477	326	1,532	6,608	457	14	NA	NA	206	101	NA	171	1,124	51,661
1995	476	2,396	4,612	17,477	1,672	12	NA	NA	42	236	NA	307	650	43,096
1996	1,864	1,367	2,744	3,744	1,203	9	NA	NA	128	113	NA	688	1,519	74,684
1997	854	363	4,104	9,879	7,025	11	NA	NA	445	264	NA	1,263	1,435	208,013
1998	592	700	13,597	1,627	5,003	18	NA	NA	555	86	NA	3,721	1,764	367,814
1999	367	24	2,925	4,599	2,737	NA	NA	NA	NA	NA	NA	NA	NA	11,917
Mean	700	921	4,481	2,806	2,776	25	723	9,900	275	184	2	972	1,272	66,062
Minimum	111	14	1,002	189	69	5	103	85	42	86	1	171	650	9,509
Maximum	1,864	3,167	21,020	17,477	15,323	123	1,763	29,473	555	324	4	3,721	2,330	367,814
SD	559	902	4,458	4,254	3,770	37	906	16,950	217	84	2	1,092	542	86,043
Total	13,997	18,417	103,056	56,112	63,837	228	2,168	29,700	1,376	1,657	6	8,748	11,451	1,519,434

NA=Not sampled.

0=Sampled, but none collected.

Mon Feb 11 10:06:17 MST 2002 ;Results; E Plant: pilgrim.74.99 ; Units: yield Pathname: P:/Intake/Seabrook-Pilgrim/Science/scode/pilgrim/tables.output.74.99.no.mussel/E.yield.pilgrim.74.99.csv

Table G3-17: Annual Entrainment at Pilgrim, By Species, Expressed as Production Foregone (in pounds)

Year	Alewife	American Plaice	American Sand Lance	Atlantic Cod	Atlantic Herring	Atlantic Mackerel	Atlantic Menhaden	Atlantic Silverside	Cunner	Fourbeard Rockling	Lumpfish	Pollock
1974	3,498	NA	NA	NA	NA	NA	8	0	382	NA	NA	146
1975	0	NA	NA	NA	NA	NA	1	425	382	NA	NA	4
1976	0	NA	NA	NA	NA	NA	4	5	382	NA	NA	28
1977	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1978	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1979	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1980	NA	NA	NA	6	1	24	7	NA	24,267	NA	NA	NA
1981	NA	NA	NA	3	3	56	5	NA	2,317	NA	NA	NA
1982	NA	NA	NA	1	1	32	118	NA	672	NA	NA	NA
1983	NA	NA	NA	2	8	44	0	NA	1,972	NA	NA	NA
1984	NA	NA	NA	3	1	7	2	NA	588	NA	NA	NA
1985	NA	NA	NA	2	2	557	14	NA	682	NA	NA	NA
1986	NA	NA	NA	1	2,139	66	7	NA	503	NA	NA	NA
1987	NA	NA	NA	1	7	21	0	NA	1,496	NA	NA	NA
1988	NA	NA	NA	1	1	795	3	NA	514	NA	NA	NA
1989	NA	NA	NA	1	1	1,394	4	NA	1,499	NA	NA	NA
1990	NA	1	68,231	700	2,456	17,208	2,506	NA	23,009	67	6,280	NA
1991	NA	2	26,318	119	1,512	143	714	NA	4,139	65	5,821	NA
1992	NA	6	121,391	217	4,690	113	719	NA	7,886	52	1,783	NA
1993	NA	25	680	202	2,479	537	72,767	NA	12,915	25	7,491	NA
1994	NA	3	514,178	851	19,316	4,073	2,167	NA	6,502	28	8,498	NA
1995	NA	2	797	275	51,088	528	7,909	NA	19,388	14	6,279	NA
1996	NA	2	4,964	1,076	13	450	5,693	NA	11,652	17	3,453	NA
1997	NA	2	1,558	492	28,877	95	33,242	NA	16,618	41	6,574	NA
1998	NA	4	46,748	342	4,757	158	23,675	NA	54,618	15,974	666	NA
1999	NA	NA	NA	212	13,442	10	12,947	NA	12,006	NA	NA	NA
Mean	1,166	5	87,207	225	6,540	1,316	7,066	143	8,886	1,809	5,205	59
Minimum	0	1	680	1	1	7	0	0	382	14	666	4
Maximum	3,498	25	514,178	1,076	51,088	17,208	72,767	425	54,618	15,974	8,498	146
SD	2,020	8	165,163	319	12,990	3,851	16,634	244	12,652	5,312	2,646	76
Total	3,498	46	784,865	4,507	130,797	26,311	162,512	430	204,389	16,284	46,846	178

NA=Not sampled.
0=Sampled, but none collected.
Mon Feb 11 10:06:10 MST 2002 ;Results; E Plant: pilgrim.74.99 ; Units: annual.prod.forg Pathname: P:/Intake/Seabrook-Pilgrim/Science/scode/pilgrim/tables.output.74.99.no.mussel/E.annual.prod.forg.pilgrim.74.99.csv

Table G3-17: Annual Entrainment at Pilgrim, By Species, Expressed as Production Foregone (in pounds) (cont.)

Year	Radiated Shanny	Rainbow Smelt	Red Hake	Rock Gunnel	Sculpin Spp.	Searobin	Tautog	Windowpane	Winter Flounder
1974	NA	26,577	NA	NA	NA	NA	NA	NA	778
1975	NA	128	NA	NA	NA	NA	NA	NA	181
1976	NA	77	NA	NA	NA	NA	NA	NA	117
1977	NA	NA	NA	NA	NA	NA	NA	NA	NA
1978	NA	NA	NA	NA	NA	NA	NA	NA	NA
1979	NA	NA	NA	NA	NA	NA	NA	NA	NA
1980	NA	NA	NA	NA	NA	NA	NA	NA	234
1981	NA	NA	NA	NA	NA	NA	NA	NA	259
1982	NA	NA	NA	NA	NA	NA	NA	NA	195
1983	NA	NA	NA	NA	NA	NA	NA	NA	106
1984	NA	NA	NA	NA	NA	NA	NA	NA	89
1985	NA	NA	NA	NA	NA	NA	NA	NA	97
1986	NA	NA	NA	NA	NA	NA	NA	NA	125
1987	NA	NA	NA	NA	NA	NA	NA	NA	27
1988	NA	NA	NA	NA	NA	NA	NA	NA	172
1989	NA	NA	NA	NA	NA	NA	NA	NA	85
1990	4,537	NA	NA	19,050	46,095	23,470	293	144,307	51,695
1991	3,959	NA	NA	58,532	78,670	35,250	129	118,674	51,519
1992	3,678	NA	NA	46,628	46	1	106	146,069	52,080
1993	5,514	NA	NA	11,576	67,962	47,153	147	362,402	50,364
1994	3,767	NA	2,152,223	96,398	210	14,693	44	174,775	116,938
1995	4,575	NA	443,276	20,623	192	34,314	80	101,062	97,529
1996	9,204	NA	1,337,095	52,014	90,006	1	179	236,264	169,001
1997	79	NA	4,653,626	6,818	544	38,421	328	223,238	470,681
1998	10,161	NA	5,794,155	23,565	83,600	12,495	967	274,388	832,257
1999	NA	NA	NA	NA	NA	NA	NA	NA	26,976
Mean	5,053	8,927	2,876,075	37,245	40,814	22,866	253	197,909	83,544
Minimum	79	77	443,276	6,818	46	1	44	101,062	27
Maximum	10,161	26,577	5,794,155	96,398	90,006	47,153	967	362,402	832,257
SD	3,031	15,285	2,263,063	28,804	40,359	17,090	284	84,241	192,674
Total	45,474	26,782	14,380,377	335,206	367,323	205,798	2,273	1,781,178	1,921,503

NA=Not sampled.
0=Sampled, but none collected.
Mon Feb 11 10:06:10 MST 2002 ;Results; E Plant: pilgrim.74.99 ; Units: annual.prod.forg Pathname: P:/Intake/Seabrook-Pilgrim/Science/scode/pilgrim/tables.output.74.99.no.mussel/E.annual.prod.forg.pilgrim.74.99.csv

G3-7 SUMMARY AND COMPARISON OF I&E AT SEABROOK AND PILGRIM

The data presented in Sections G3-4 and G3-6 indicate that the fish species most often impinged at both Seabrook and Pilgrim are fishery species. At Seabrook, the most frequently impinged fishery species are winter flounder, red hake and Atlantic silverside. At Pilgrim, the most abundant fishery species in impingement collections are Atlantic silverside, Atlantic herring, rainbow smelt, and Atlantic menhaden.

Entrainment rates at both facilities are several orders of magnitude higher than impingement rates. At Seabrook, the fish species most frequently entrained include the fishery species Atlantic mackerel, winter flounder, and red hake. At Pilgrim, the fishery species most frequently entrained include Atlantic mackerel and cunner. Entrainment losses of some forage fish are also high at both facilities, including fourbeard rockling, lumpfish, and rock gunnel at Seabrook, and American sand lance, fourbeard rockling, and lumpfish at Pilgrim.

The data presented in Sections G3-4 and G3-6 also indicate that I&E at Seabrook's offshore intake is substantially lower than I&E at Pilgrim's nearshore intake. EPA compared age 1 equivalent losses for years when both facilities were operating, including 1990-1993 and 1995-1998 (Seabrook was shut down during much of 1994 and so this year was not considered in the comparison). Total losses averaged over these years for the 32 species that are either impinged or entrained at both facilities indicate that impingement averages 68% less at Seabrook and entrainment averages 58% less.

G3-8 POTENTIAL BIASES AND UNCERTAINTIES IN I&E ESTIMATES

Pilgrim and Seabrook used different methods to estimate annual I&E, and therefore the I&E estimates of the two facilities may not be strictly comparable. In addition, Seabrook was shut down during parts of 1994 and 1997 (Normandeau Associates, 1999). Table G3-18 outlines the main factors that should be taken into account in comparing I&E losses at the two facilities.

Table G3-18: Differences in Methods Used by Pilgrim and Seabrook to Estimate Annual I&E and Potential Effects on EPA's Results

Estimation Parameters	Pilgrim	Seabrook	Effect on Comparison of Facility Losses
Mesh size for entrainment sampling	0.202 and 0.333 mm stage 1 and 2 larvae were adjusted for mesh extrusion	0.505 mm No adjustment	0
Flow used for density calculations	Design flow	Operational flow	Likely to overestimate the difference between the two facilities.
Entrainment sampling frequency	2-6 times per month	4 times per month	U
Impingement sampling frequency	8 hours 3 times per week	2 to 3 times per week	U
Adjustment for day/night sampling	Sampling day and night	No sampling at night and no adjustment	Likely to underestimate the difference between the two facilities.

U = Uncertain (could underestimate or overestimate the difference between the two facilities)..
0 = No effect.

The effect of various mesh sizes seems to have been adjusted properly at each facility, so differences in mesh sizes appear unimportant in comparing losses. At Pilgrim, mesh correction values were applied to both eggs and larvae to decrease the effect of different mesh sizes (0.202 and 0.333 mm) on I&E estimates. In contrast, Seabrook did not apply mesh correction values because a comparison of sampling efficiency with 0.505 mm and 0.333 mm mesh sizes in 1998 indicated that such a correction was unnecessary. Seabrook found that the flow through each mesh size and the total volume sampled for each mesh size were identical, and there were no significant differences in ichthyoplankton densities based on sampling with the different mesh sizes (Normandeau Associates, 1999).

Another potentially important difference in methods concerns the flow volume used to calculate entrainment density. Seabrook used the weekly cooling water volume measured during the week an entrainment sample was taken, whereas Pilgrim used the full-load flow. Pilgrim used this value even if the station was out of service and less than full capacity was being

circulated. Therefore, Pilgrim may have overestimated annual I&E losses, which would result in an overestimate of any differences in loss rates between the two facilities.

Time of day of sampling may also affect estimates of losses. At Pilgrim, entrainment sampling was conducted at least once a month at night, whereas prior to 1998 entrainment sampling at Seabrook took place only during the day. Different sets of organisms are susceptible to entrainment in the day and the night. Therefore, by sampling only during the day, Seabrook may have underestimated entrainment, resulting in an underestimate of differences in I&E rates at the two facilities.

Entrainment sampling frequencies differed between Seabrook and Pilgrim, but the effect of sampling frequency on I&E has never been studied. Therefore, the potential importance of various entrainment sampling frequencies on a comparison of losses between Seabrook and Pilgrim is unknown.

Methods used to estimate annual impingement numbers also differed between the two facilities. Once or twice a week, Seabrook collected all fish impinged on the traveling screens and summed the fish impinged in the individual screenwashes to obtain yearly estimates. In contrast, Pilgrim collected impinged fish over an 8 hour period three times per week and estimated hourly impingement rates by dividing the numbers of fish impinged during the monitoring period by the numbers of hours of monitoring. These rates were then multiplied by 24 hours and 365 days to obtain annual impingement numbers. The effect of these differences in collection methods is uncertain.

Chapter G4:

Value of I&E Losses at the Seabrook and Pilgrim Facilities Based on Benefits Transfer Techniques

This chapter presents the results of EPA's evaluation of the economic losses associated with I&E at the Seabrook and Pilgrim facilities using benefits transfer techniques. Section G4-1 provides an overview of the valuation approach, Section G4-2 discusses the value of losses to recreational fisheries, Section G4-3 discusses the value of commercial fishery losses, Section G4-4 discusses values of forage losses, Section G4-5 discusses nonuse values, and Section G4-6 summarizes benefits transfer results.

G4-1 OVERVIEW OF VALUATION APPROACH

I&E at Seabrook and Pilgrim affect recreational and commercial fisheries as well as forage species that contribute to the biomass of fishery species. EPA evaluated all these species groups to capture the total economic impact of I&E at Seabrook and Pilgrim.

Recreational fishery impacts are based on benefits transfer methods, applying results from nonmarket valuation studies. Commercial fishery impacts are based on commodity prices for the individual species. The economic value of forage species losses is determined by estimating the replacement cost of these fish if they were to be restocked with hatchery fish, and by considering the foregone biomass production of forage fish resulting from I&E losses and the consequential foregone production of commercial and recreational species that use the forage species as a prey base. All of these methods are explained in further detail in Chapters A5 and A9 of this document.

Many of the I&E-impacted fish species at Seabrook and Pilgrim are harvested both recreationally and commercially. To avoid double-counting the economic impacts of I&E on these species, EPA determined the proportion of total species landings attributable to recreational and commercial fishing, and applied this proportion to the impacted fishery catch. For example, if 30 percent of the landed numbers of one species are harvested commercially at a site, then 30 percent of the estimated catch of I&E-impacted fish are assigned to the increase in commercial landings. The remaining 70 percent of the estimated total landed number of I&E-impacted adult equivalents are assigned to the recreational landings.

The National Marine Fisheries Service (NMFS) provides both recreational and commercial fishery landings data by state. To determine what proportions of total landings per state occur in the recreational or commercial fishery, EPA summed the landings data for the recreational and commercial fishery, and then divided by each category to get the corresponding percentage. The percentages applied in this analysis are presented in Table G4-1.

Table G4-1: Percentages of Total Impacts in the Recreational and Commercial Fisheries
of Selected Species at Seabrook and Pilgrim Facilities

Fish Species	Percent Impacts to Recreational Fishery	Percent Impacts to Commercial Fishery
Alewife	0	100
American plaice	0	100
Atlantic cod	6	94
Atlantic herring	0	100
Atlantic mackerel	62	38
Atlantic menhaden	0	100
Atlantic silverside	0	100
Blueback herring	100	0
Bluefish	50	50
Butterfish	7	93
Cunner	87	13
Little skate	0	100
Pollock	2	98
Red hake	0	100
Scup	45	55
Searobin	100	0
Striped bass	86	14
Tautog	63	37
White perch	89	11
Windowpane	3	97
Winter flounder	70	30

Fri Feb 08 10:11:00 MST 2002 ; TableA:Percentages of total impacts occurring to the commercial and
recreational fisheries of selected species; Plant: seabrook.90.98 ; Pathname: P:/Intake/Seabrook-
Pilgrim/Science/scode/seabrook/tables.output.90.98.no.mussel/TableA.Perc.of
total.impacts.seabrook.90.98.csv

As discussed in Chapter A5 of Part A of this document, the yield estimates presented in Chapter G3 represent the total pounds of foregone yield for both the commercial and recreational catch combined. For the economic valuation discussed in this chapter, Table G4-1 partitions total yield between commercial and recreational fisheries based on the landings in each fishery. Because the economic evaluation of recreational yield is based on numbers of fish rather than pounds, foregone recreational yield was converted to numbers of fish. This conversion was based on the average weight of harvestable fish of each species. Tables G4-2 and G4-3 show these conversions for the Seabrook and Pilgrim impingement data presented in Chapter G3, and Tables G4-4 and G4-5 displays the conversions for entrainment data. Note that the numbers of foregone recreational fish harvested are typically lower than the numbers of age 1 equivalent losses, since the age of harvest of most fish is greater than age 1.

Table G4-2: Summary of Seabrook's Mean Annual Impingement of Fishery Species

Species	Impingement Count (#)	Age 1 Equivalents (#)	Total Catch (#)	Total Yield (lbs)	Commercial Catch (#)	Commercial Yield (lbs)	Recreational Catch (#)	Recreational Yield (lbs)
Alewife	508	679	7	3	7	3	0	0
Atlantic herring	287	334	104	46	104	46	0	0
Blueback herring	50	58	2	0	0	0	2	0
Butterfish	28	38	3	2	3	2	0	0
Cod Atlantic	99	118	20	39	19	36	1	2
Cunner	232	323	7	1	1	0	6	1
Little skate	110	141	37	29	37	29	0	0
Mackerel, Atlantic	2	3	1	0	0	0	0	0
Menhaden, Atlantic	12	14	5	5	5	5	0	0
Pollock	643	707	154	1,038	151	1,017	3	21
Rainbow smelt	701	949	21	7	9	3	12	4
Red hake	1,041	1,333	394	238	394	238	0	0
Scup	3	4	0	1	0	0	0	0
Searobin	4	5	0	0	0	0	0	0
Silverside, Atlantic	1,040	1,871	58	1	58	1	0	0
Striped bass	1	1	0	1	0	0	0	1
Tautog	7	7	2	8	1	3	1	5
White perch	1	1	0	0	0	0	0	0
Windowpane	664	797	295	59	286	57	9	2
Winter flounder	1,032	1,136	286	358	86	107	200	251
Total	6,465	8,519	1,396	1,837	1,160	1,548	236	289

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Table G4-3: Summary of Pilgrim's Mean Annual Impingement of Fishery Species

Species	Impingement Count (#)	Age 1 Equivalents (#)	Total Catch (#)	Total Yield (lbs)	Commercial Catch (#)	Commercial Yield (lbs)	Recreational Catch (#)	Recreational Yield (lbs)
Alewife	3,250	4,343	43	22	43	22	0	0
Atlantic cod	252	302	52	99	49	93	3	2
Atlantic mackerel	2	3	1	0	0	0	0	0
Blueback herring	612	703	15	5	0	0	15	3
Bluefish	2	2	1	1	0	1	0	1
Butterfish	297	399	29	19	27	18	2	1
Cunner	295	411	9	2	1	0	7	1
Herring, Atlantic	7,593	8,836	2,743	1,225	2,743	1,225	0	0
Little skate	61	78	20	16	20	16	0	0
Menhaden, Atlantic	5,048	6,165	2,011	2,111	2,011	2,111	0	0
Pollock	30	33	7	48	7	47	0	0
Rainbow smelt	5,118	6,929	154	52	63	21	91	14
Red hake	178	229	68	41	68	41	0	0
Scup	97	114	13	21	7	12	6	4
Searobin	56	69	6	3	0	0	6	2
Silverside, Atlantic	11,587	20,842	651	8	651	8	0	0
Striped bass	6	9	1	13	0	2	1	5
Tautog	183	201	56	223	21	83	35	54
White perch	55	73	0	0	0	0	0	1
Windowpane	236	284	105	21	102	20	3	0
Winter flounder	1,039	1,144	287	361	86	108	201	98
Total	35,997	51,168	6,270	4,292	5,900	3,827	371	186

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Table G4-4: Summary of Seabrook's Mean Annual Entrainment of Fishery Species

Species	Entrainment Count (#)	Age 1 Equivalents (#)	Total Catch (#)	Total Yield (lbs)	Commercial Catch (#)	Commercial Yield (lbs)	Recreational Catch (#)	Recreational Yield (lbs)
Alewife	0	0	0	0	0	0	0	0
Atlantic herring	4,767,333	13,900	4,315	1,927	4,315	1,927	0	0
Bluefish	11,111	1	0	0	0	0	0	0
Butterfish	55,556	27	2	1	2	1	0	0
Cod, Atlantic	10,007,778	2,330	402	763	378	717	24	46
Cunner	35,403,667	184,427	3,840	832	499	108	3,341	724
Little skate	0	0	0	0	0	0	0	0
Mackerel, Atlantic	245,390,667	1,058	207	146	79	56	128	91
Menhaden, Atlantic	301,556	19	6	6	6	6	0	0
Plaice, American	27,435,889	1,167	230	134	230	134	0	0
Pollock	660,390	7	2	10	2	10	0	0
Rainbow smelt	69,778	7,730	171	58	70	24	101	34
Red hake	93,151,889	362	107	65	107	65	0	0
Searobin	11,111	227	18	11	0	0	18	11
Tautog	128,444	7	2	8	1	3	1	5
Windowpane	25,726,667	10,317	3,818	761	3,703	738	115	23
Winter flounder	244,035,113	78,046	19,615	24,602	5,885	7,381	13,731	17,221
Commercial and Recreational Species Total	687,156,949	299,623	32,736	29,323	15,276	11,168	17,460	18,155

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Table G4-5: Summary of Pilgrim's Mean Annual Entrainment of Fishery Species

Species	Entrainment Count (#)	Age 1 Equivalents (#)	Total Catch (#)	Total Yield (lbs)	Commercial Catch (#)	Commercial Yield (lbs)	Recreational Catch (#)	Recreational Yield (lbs)
Alewife	323,435	0	0	0	0	0	0	0
Atlantic cod	6,291,173	2,138	369	700	347	658	22	32
Atlantic mackerel	1,034,964,861	6,659	1,303	921	495	350	808	439
Cunner	2,714,603,689	993,500	20,688	4,481	2,689	582	17,999	3,449
Herring, Atlantic	6,942,590	20,243	6,284	2,806	6,284	2,806	0	0
Menhaden, Atlantic	81,926,445	8,105	2,644	2,776	2,644	2,776	0	0
Plaice, American	11,260,136	221	43	25	43	25	0	0
Pollock	42,751,473	492	107	723	105	708	2	2
Rainbow smelt	10,112,547	1,323,137	29,309	9,900	12,017	4,059	17,292	674
Red hake	31,075,325	1,545	457	275	457	275	0	0
Searobin	1,970,043	3,698	300	184	0	0	300	64
Silverside, Atlantic	1,435,668	5,087	159	2	159	2	0	0
Tautog	7,512,870	875	242	972	90	360	153	212
Windowpane	83,547,445	17,258	6,387	1,272	6,195	1,234	192	-13
Winter flounder	30,900,375	209,571	52,672	66,062	15,802	19,819	36,870	40,908
Total	4,065,618,075	2,592,529	120,963	91,099	47,326	33,654	73,638	45,794

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G4-2 ECONOMIC VALUE OF AVERAGE ANNUAL LOSSES TO RECREATIONAL FISHERIES RESULTING FROM I&E AT SEABROOK AND PILGRIM FACILITIES

G4-2.1 Economic Values of Recreational Fishery Losses from the Consumer Surplus Literature

There is a large literature that provides willingness-to-pay (WTP) values for increases in recreational catch rates. These increases in value are benefits to the anglers, and are often referred to by economists as "consumer surplus." In applying this literature to value I&E impacts, EPA focused on changes in consumer surplus per additional fish caught.

When using values from the existing literature as proxies for the value of a trip or fish at a site not studied, it is important to select values for similar areas and species. Table G4-6 gives a summary of several studies that are closest to the Cape Cod and Ipswich Bay fisheries in the vicinity of the Seabrook and Pilgrim stations.

Table G4-6: Selected Valuation Studies for Estimating Changes in Catch Rates

Authors	Study Location and Year	Item Valued	Value Estimate ($2000)[a]	
McConnell and Strand (1994)	Mid- and south Atlantic coast, anglers targeting specific species, 1988	Catch rate increase of 1 fish per trip for NY[b]	NY flatfish	$5.35
			NY small game fish	$9.54
			NY bottom fish	$2.54
Tudor et al. (2002)[c]	Delaware Estuary, 2001	Catch rate increase of 1 fish per trip	DE weakfish	$11.50
			DE striped bass	$18.14
			DE bluefish	$3.94
			DE Flounder	$3.92
Hicks et al. (1999)	Mid-Atlantic coast, 1994	Catch rate increase of 1 fish per trip, from historical catch rates at all sites, for NH and MA	NH and MA flatfish	$5.29
			NH and MA small game fish	$3.69
			NH and MA bottom fish	$2.43

[a] The recreational WTP values reported in subsequent tables are incorrectly stated as being slightly less than the values reported here. This indicates that the recreational losses in those tables are moderately understated.

[b] Value was reported as "two month value per angler for a half fish catch increase per trip." From 1996 National Survey of Fishing, Hunting and Wildlife-Associated Recreation (U.S. DOI, 1997), the average saltwater angler takes 1.5 trips in a 2 month period. Therefore, to convert to a "1 fish per trip" value, EPA divided the 2 month value by 1.5 trips and then multiplied it by 2, assuming the value of a fish was linear.

[c] See chapter B5 of this document. These values were not applied in the analysis, but remain listed here for comparison.

McConnell and Strand (1994) estimated fishery values for the mid- and south Atlantic states using data from the NMFS Survey. They created a random utility model of fishing behavior for nine states, the northernmost being New York. In this model they specified four categories of fish: small gamefish (e.g., striped bass), flatfish (e.g., flounder), bottomfish (e.g., weakfish, spot, Atlantic croaker, perch), and big gamefish (e.g., shark). For each fish category, they estimated per angler values for access to marine waters and for an increase in catch rates.

Tudor et al. (2002; see chapter B5 of this document) applied a random utility model (RUM) to the recreational fishery impacts associated with I&E in the Delaware Estuary. The methods, data, and results of the Tudor et al. (2002; see chapter B5 of this document) study are discussed in greater detail in Chapters A10 and B5 of this document. These values were not applied in the Seabrook-Pilgrim analysis because the McConnell and Strand (1994) study is more geographically precise, but they are listed here as a basis for comparison.

Hicks et al. (1999) used the same method as McConnell and Strand (1994) but estimated values for a day of fishing and an increase in catch rates for the Atlantic states from Virginia north to Maine. Their estimates were generally lower than those of McConnell and Strand (1994) and may serve as a lower bound for the values of fish.

G4-2.2 Economic Values of Recreational Fishery Losses at Seabrook and Pilgrim

EPA estimated the average annual economic value of Seabrook and Pilgrim I&E impacts to recreational fisheries using the I&E estimates presented in Tables G4-2 through G4-5 and the economic values presented in Table G4-6. Because none of the studies in Table G4-6 considered the region around Seabrook and Pilgrim directly, EPA created a lower and upper value

for New Hampshire and Massachusetts for each impacted recreational species, and then calculated a weighted average value based on the proportion of landings from each state. Results are presented in Tables G4-7 through G4-10. The estimated total losses at Seabrook to the recreational fisheries range from $1,100 to $1,300 for impingement per year (Table G4-7), and from $75,000 to $87,200 annually for entrainment (Table G4-8). The estimated losses at Pilgrim range from $1,500 to $2,100 for impingement per year (Table G4-9), and from $287,900 to $408,800 annually for entrainment (Table G4-10).

Table G4-7: Average Annual Impingement of Recreational Fishery Species at Seabrook and Associated Economic Values

Species	Loss to Recreational Catch from Impingement (number of fish)	Recreational Value/Fish		Annual Loss in Recreational Value from Impingement ($2000)	
		Low	High	Low	High
Blueback herring	2	$2.28	$2.73	$5	$6
Butterfish	< 1	$3.75	$8.56	$1	$2
Cod Atlantic	1	$2.28	$2.46	$3	$3
Cunner	6	$2.28	$2.73	$13	$16
Mackerel, Atlantic	< 1	$3.75	$8.56	$1	$3
Pollock	3	$2.28	$2.41	$7	$7
Rainbow smelt	12	$3.75	$8.56	$46	$106
Scup	< 1	$2.28	$2.73	$0	$1
Searobin	< 1	$2.28	$2.56	$1	$1
Striped bass	< 1	$3.75	$8.56	$0	$1
Tautog	1	$2.28	$2.48	$3	$3
Windowpane	9	$4.80	$5.51	$42	$49
Winter flounder	200	$4.80	$5.49	$959	$1,097
Total	236			$1,083	$1,295

Note: Numbers of fish are rounded here but not in calculations.
Fri Feb 08 10:11:06 MST 2002 ; TableB: recreational losses and value for selected species; Plant: seabrook.90.98 ; type: I
Pathname: P:/Intake/Seabrook-Pilgrim/Science/scode/seabrook/tables.output.90.98.no.mussel/TableB.rec.losses.seabrook.90.98.I.csv

Table G4-8: Average Annual Entrainment of Recreational Fishery Species at Seabrook and Associated Economic Values

Species	Loss to Recreational Catch from Entrainment (number of fish)	Recreational Value/Fish		Annual Loss in Recreational Value from Entrainment ($2000)	
		Low	High	Low	High
Bluefish	< 1	$3.75	$8.56	$0	$1
Butterfish	< 1	$3.75	$8.56	$1	$1
Cod Atlantic	24	$2.28	$2.46	$55	$59
Cunner	3,341	$2.28	$2.73	$7,618	$9,121
Mackerel, Atlantic	128	$3.75	$8.56	$481	$1,098
Rainbow smelt	101	$3.75	$8.56	$379	$865
Searobin	18	$2.28	$2.56	$42	$47
Tautog	1	$2.28	$2.48	$3	$3
Windowpane	115	$4.80	$5.51	$550	$631
Winter flounder	13,731	$4.80	$5.49	$65,908	$75,382
Total	17,460			$75,036	$87,209

Note: Numbers of fish are rounded here but not in calculations.
Fri Feb 08 10:11:15 MST 2002 ; TableB: recreational losses and value for selected species; Plant: seabrook.90.98 ; type: E Pathname:
P:/Intake/Seabrook-Pilgrim/Science/scode/seabrook/tables.output.90.98.no.mussel/TableB.rec.losses.seabrook.90.98.E.csv

Table G4-9: Average Annual Impingement of Recreational Fishery Species at Pilgrim and Associated Economic Values

Species	Loss to Recreational Catch from Impingement (number of fish)	Recreational Value/Fish		Annual Loss in Recreational Value from Impingement ($2000)	
		Low	High	Low	High
Atlantic cod	3	$2.28	$2.46	$7	$8
Atlantic mackerel	<1	$3.75	$8.56	$1	$3
Blueback herring	15	$2.28	$2.73	$33	$40
Bluefish	<1	$3.75	$8.56	$1	$2
Butterfish	2	$3.75	$8.56	$8	$17
Cunner	7	$2.28	$2.73	$17	$20
Pollock	<1	$2.28	$2.41	$0	$0
Rainbow smelt	91	$3.75	$8.56	$340	$775
Scup	6	$2.28	$2.73	$14	$17
Searobin	6	$2.28	$2.56	$13	$14
Striped bass	1	$3.75	$8.56	$4	$9
Tautog	35	$2.28	$2.48	$80	$87
Windowpane	3	$4.80	$5.51	$15	$17
Winter flounder	201	$4.80	$5.49	$966	$1,105
Total	371			$1,499	$2,115

Note: Numbers of fish are rounded here but not in calculations.
Thu Feb 07 17:19:25 MST 2002 ; TableB: recreational losses and value for selected species; Plant: pilgrim.74.99 ; type: I
Pathname: P:/Intake/Seabrook-
Pilgrim/Science/scode/pilgrim/tables.output.74.99.no.mussel/TableB.rec.losses.pilgrim.74.99.I.csv

Table G4-10: Average Annual Entrainment of Recreational Fishery Species at Pilgrim and Associated Economic Values.

Species	Loss to Recreational Catch from Entrainment (number of fish)	Recreational Value/Fish		Annual Loss in Recreational Value from Entrainment ($2000)	
		Low	High	Low	High
Atlantic cod	22	$2.28	$2.46	$51	$54
Atlantic mackerel	808	$3.75	$8.56	$3,030	$6,916
Cunner	17,999	$2.28	$2.73	$41,037	$49,136
Pollock	2	$2.28	$2.41	$5	$5
Rainbow smelt	17,292	$3.75	$8.56	$64,847	$148,023
Searobin	300	$2.28	$2.56	$684	$768
Tautog	153	$2.28	$2.48	$348	$378
Windowpane	192	$4.80	$5.51	$920	$1,056
Winter flounder	36,870	$4.80	$5.49	$176,978	$202,418
Total	73,638			$287,897	$408,755

Note: Numbers of fish are rounded here but not in calculations.
Thu Feb 07 17:19:34 MST 2002 ; TableB: recreational losses and value for selected species; Plant: pilgrim.74.99 ; type: E Pathname:
P:/Intake/Seabrook-Pilgrim/Science/scode/pilgrim/tables.output.74.99.no.mussel/TableB.rec.losses.pilgrim.74.99.E.csv

G4-3 ECONOMIC VALUE OF AVERAGE ANNUAL COMMERCIAL FISHERY LOSSES RESULTING FROM I&E AT SEABROOK AND PILGRIM

Values for commercial fishing losses are relatively straightforward because commercially caught fish are a commodity with a market price (blue mussel are not included in EPA's valuation of commercial fishery losses as discussed in the accompanying box). Losses to commercial catch (pounds) resulting from I&E at Seabrook are presented in Table G4-2 (for impingement) and Table G4-4 (for entrainment). Commercial losses at Pilgrim are presented in Table G4-3 (for impingement) and Table G4-5 (for entrainment). The market value of foregone commercial yield at Seabrook is $978 for impingement per year (Table G4-11), and $11,542 annually for entrainment (Table G4-12). The market value of foregone commercial yield at Pilgrim is $517 for impingement per year (Table G4-13), and $30,787 annually for entrainment (Table G4-14).

> Recorded impingement and entrainment of blue mussel at Seabrook and Pilgrim ranges from 2.2 trillion in 1974 to 19.1 trillion in 1975. Corresponding yield ranges from 1.2 to 10.4 billion pounds. Based on a commercial value in some parts of New England of $0.24 per pound, these losses equate to $2.6 billion annually. However, blue mussel in the area around Seabrook and Pilgrim are considered a nuisance species because they clog intake screens (Entergy Nuclear Generation Company, 2000) and compete with commercially desirable species, such as soft shell clam (Mike Hickey, MA Division of Marine Fisheries, personal communication, January 16, 2002). As a result, EPA did not consider blue mussel losses in its benefits analysis.

Table G4-11: Average Annual Impingement of Commercial Fishery Species at Seabrook and Associated Economic Values

Species	Loss to Commercial Catch from Impingement (lb of fish)	Commercial Value (lb of fish)	Annual Loss in Commercial Value from Impingement ($2000)
Alewife	3	$0.17	$1
Atlantic herring	46	$0.05	$2
Butterfish	2	$0.47	$1
Cod Atlantic	36	$0.83	$30
Little skate	29	$0.19	$6
Menhaden, Atlantic	5	$0.04	$0
Pollock	1,017	$0.69	$702
Rainbow smelt	3	$0.20	$1
Red hake	238	$0.22	$52
Silverside, Atlantic	1	$0.54	$0
Tautog	3	$0.64	$2
Windowpane	57	$0.57	$32
Winter flounder	107	$1.38	$148
Total	1,548		$978

Fri Feb 08 10:11:07 MST 2002 ; TableC: commerical losses and value for selected species; Plant: seabrook.90.98 ; type: I Pathname: P:/Intake/Seabrook-Pilgrim/Science/scode/seabrook/tables.output.90.98.no.mussel/TableC.comm.losses.seabrook.90.98.I.csv

Table G4-12: Average Annual Entrainment of Commercial Fishery Species at Seabrook and Associated Economic Values

Species	Loss to Commercial Catch from Entrainment (lb of fish)	Commercial Value (lb of fish)	Annual Loss in Commercial Value from Entrainment ($2000)
Atlantic herring	1,927	$0.05	$96
Butterfish	1	$0.47	$1
Cod Atlantic	717	$0.83	$595
Cunner	108	$0.37	$40
Mackerel, Atlantic	56	$0.28	$16
Menhaden, Atlantic	6	$0.04	$0
Plaice, American	134	$1.20	$160
Pollock	10	$0.69	$7
Rainbow smelt	24	$0.20	$5
Red hake	65	$0.22	$14
Tautog	3	$0.64	$2
Windowpane	738	$0.57	$421
Winter flounder	7,381	$1.38	$10,185
Total	11,168		$11,542

Fri Feb 08 10:11:16 MST 2002 ; TableC: commerical losses and value for selected species; Plant: seabrook.90.98 ; type: E
Pathname: P:/Intake/Seabrook-
Pilgrim/Science/scode/seabrook/tables.output.90.98.no.mussel/TableC.comm.losses.seabrook.90.98.E.csv

Table G4-13: Average Annual Impingement of Commercial Fishery Species at Pilgrim and Associated Economic Values

Species	Loss to Commercial Catch from Impingement (lb of fish)	Commercial Value (lb of fish)	Annual Loss in Commercial Value from Impingement ($2000)
Alewife	22	$0.17	$4
Atlantic cod	93	$0.83	$77
Bluefish	1	$0.25	$0
Butterfish	18	$0.47	$8
Herring, Atlantic	1,225	$0.05	$61
Little skate	16	$0.19	$3
Menhaden, Atlantic	2,111	$0.04	$84
Pollock	47	$0.69	$33
Rainbow smelt	21	$0.20	$4
Red hake	41	$0.22	$9
Scup	12	$1.05	$12
Silverside, Atlantic	8	$0.54	$4
Striped bass	2	$1.50	$3
Tautog	83	$0.64	$53
Windowpane	20	$0.57	$12
Winter flounder	108	$1.38	$149
Total	3,827		$517

Thu Feb 07 17:19:25 MST 2002 ; TableC: commerical losses and value for selected species; Plant: pilgrim.74.99 ; type: I Pathname:
P:/Intake/Seabrook-Pilgrim/Science/scode/pilgrim/tables.output.74.99.no.mussel/TableC.comm.losses.pilgrim.74.99.I.csv

Table G4-14: Average Annual Entrainment of Commercial Fishery Species at Pilgrim and Associated Economic Values

Species	Loss to Commercial Catch from Entrainment (lb of fish)	Commercial Value (lb of fish)	Annual Loss in Commercial Value from Entrainment ($2000)
Atlantic cod	658	$0.83	$546
Atlantic mackerel	350	$0.28	$98
Cunner	582	$0.37	$216
Herring, Atlantic	2,806	$0.05	$140
Menhaden, Atlantic	2,776	$0.04	$111
Plaice, American	25	$1.20	$30
Pollock	708	$0.69	$489
Rainbow smelt	4,059	$0.20	$812
Red hake	275	$0.22	$61
Silverside, Atlantic	2	$0.54	$1
Tautog	360	$0.64	$230
Windowpane	1,234	$0.57	$703
Winter flounder	19,819	$1.38	$27,350
Total	33,654		$30,787

Thu Feb 07 17:19:34 MST 2002 ; TableC: commerical losses and value for selected species; Plant: pilgrim.74.99 ; type: E Pathname: P:/Intake/Seabrook-Pilgrim/Science/scode/pilgrim/tables.output.74.99.no.mussel/TableC.comm.losses.pilgrim.74.99.E.csv

EPA has expressed changes to commercial activity thus far as changes from dockside market prices. However, to determine the total economic impact from changes to the commercial fishery, EPA determined the losses experienced by producers (watermen), wholesalers, retailers, and consumers.

The total social benefits (economic surplus) are greater than the increase in dockside landings, because the increased landings by commercial fishermen contribute to economic surplus in each of a multi-tiered set of markets for commercial fish. The total economic surplus impact thus is valued by examining the multi-tiered markets through which the landed fish are sold, according to the methods and data detailed in Chapter A9.

The first step of the analysis involves a fishery-based assessment of I&E-related changes in commercial landings (pounds of commercial species as sold dockside by commercial harvesters). The results of this dockside landings value step are described above. The next steps then entail tracking the anticipated additional economic surplus generated as the landed fish pass from dockside transactions to other wholesalers, retailers and, ultimately, consumers. The resulting total economic surplus measures include producer surplus to the watermen who harvest the fish, as well as the rents and consumer surplus that accrue to buyers and sellers in the sequence of market transactions that apply in the commercial fishery context.

To estimate producer surplus from the landings values, EPA relied on empirical results from various researchers that can be used to infer producer surplus for watermen based on gross revenues (landings times wholesale price). The economic literature (Huppert, 1990; Rettig and McCarl, 1985) suggests that producer surplus values for commercial fishing ranges from 50 to 90 percent of the market value. In assessments of Great Lakes fisheries, an estimate of approximately 40% has been derived as the relationship between gross revenues and the surplus of commercial fishermen (Cleland and Bishop, 1984, Bishop, personal communication, 2002). For the purposes of this study, EPA believes producer surplus to watermen is probably in the range of 40% to 70% of dockside landings values.

Producer surplus is one portion of the total economic surplus impacted by increased commercial stocks — the total benefits are comprised of the economic surplus to producers, wholesalers, processors, retailers, and consumers. Primary empirical research deriving "multi-market" welfare measures for commercial fisheries have estimated that surplus accruing to commercial anglers amount to approximately 22% of the total surplus accruing to watermen, retailers and consumers combined (Norton et al., 1983; Holt and Bishop, 2002). Thus, total economic surplus across the relevant commercial fisheries multi-tiered markets can be estimated as approximately 4.5 times greater than producer surplus alone (given that producer

surplus is roughly 22% of the total surplus generated). This relationship is applied in the case studies to estimate total surplus from the projected changes in commercial landings.

Applying this method, estimates of the economic loss to commercial fisheries resulting from I&E at Seabrook range from $1,800 to $3,100 per year for impingement and from $21,000 to $36,700 per year for entrainment. For I&E at Pilgrim, estimates range from $900 to $1,600 per year for impingement and from $56,000 to $98,000 per year for entrainment.

G4-4 ECONOMIC VALUE OF FORAGE FISH LOSSES

Many species affected by I&E are not commercially or recreationally fished. For the purposes in this study, EPA referred to these species as forage fish. Forage fish are species that are prey for other species and are important components of aquatic food webs. Based on the analysis of I&E data presented in Chapter G3, Table G4-15 summarizes impingement losses of forage species at Seabrook and Table G4-16 summaries entrainment losses. Impingement of forage species at Pilgrim is summarized in Table G4-17 and entrainment losses are summarized in Table G4-18. The following sections discuss the economic valuation of these losses using two alternative valuation methods.

Table G4-15: Summary of Seabrook's Mean Annual Impingement of Forage Species

Species	Impingement Count (#)	Age 1 Equivalents (#)	Production Foregone (lbs)
American sand lance	476	696	4
Fourbeard rockling	3	4	0
Grubby	1,156	1,418	86
Killifish striped	8	11	0
Lumpfish	391	428	14
Northern pipefish	285	388	0
Radiated shanny	20	24	0
Rock gunnel	710	864	4
Sculpin spp.	401	492	30
Threespine stickleback	171	243	0
Forage species total	3,621	4,568	138

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Pilgrim\Science\scode\seabrook\tables.output.90.98.no.mussel\flowchart.IMP.NEW.xls

Table G4-16: Summary of Seabrook's Mean Annual Entrainment of Forage Species

Species	Impingement Count (#)	Age 1 Equivalents (#)	Production Foregone (lbs)
American sand lance	13,329,111	397,513	14,937
Fourbeard rockling	58,510,333	165,150	3,931
Grubby	14,012,778	252,098	24,840
Killifish striped	0	0	0
Lumpfish	31,862,889	5,014	24,655
Northern pipefish	11,111	782	30
Radiated shanny	1,700,222	144,945	480
Rock gunnel	22,719,111	3,217,922	35,278
Sculpin spp.	1,634,444	29,405	2,897
Threespine stickleback	0	0	0
Forage species total	143,779,999	4,212,828	107,049

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Table G4-17: Summary of Pilgrim's Mean Annual Impingement of Forage Species

Species	Impingement Count (#)	Age 1 Equivalents (#)	Production Foregone (lbs)
American sand lance	19	27	0
Bay anchovy	11	18	0
Fourbeard rockling	2	2	0
Grubby	717	879	53
Hogchoker	2	2	0
Killifish striped	66	90	1
Lumpfish	198	217	7
Northern pipefish	87	118	0
Radiated shanny	45	54	0
Rock gunnel	63	77	0
Sculpin spp.	11	13	1
Threespine stickleback	83	118	0
Total	1,304	1,616	63

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Table G4-18: Summary Pilgrim's Mean Annual Entrainment of Forage Species

Species	Entrainment Count (#)	Age 1 Equivalents (#)	Production Foregone (lbs)
American sand lance	138,023,372	4,116,258	87,207
Fourbeard rockling	94,252,169	411,189	1,809
Lumpfish	6,489,657	1,080	5,205
Radiated shanny	19,289,027	1,644,402	5,053
Rock gunnel	34,332,210	4,862,795	37,245
Sculpin spp.	40,841,427	734,760	40,814
Total	333,227,862	11,770,483	177,333

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Pilgrim\Science\scode\pilgrim\tables.output.74.99\flowchart.ENT.NEW.csv

G4-4.1 Replacement Cost of Fish

The replacement value of fish can be used in several instances. First, if a fish kill of a fishery species is mitigated by stocking of hatchery fish, then losses to the commercial and recreational fisheries would be reduced, but fish replacement costs would still be incurred and should be accounted for. Second, if the fish are not caught in the commercial or recreational fishery, but are important as forage or bait, the replacement value can be used as a lower bound estimate of their value (it is a lower bound because it would not consider how reduction in their stock may affect other species' stocks). Third, where there are not enough data to allow calculation of value losses to the recreational and commercial fisheries, replacement cost can be used as a proxy for lost fishery values. Typically the consumer or producer surplus is greater than fish replacement costs, and replacement costs typically omit problems associated with restocking programs (e.g., limiting genetic diversity).

The cost of replacing forage fish lost to I&E has two main components. The first component is the cost of raising the replacement fish. Tables G4-19 and G4-20 display the replacement costs of some of the forage fish species known to be impinged or entrained at Seabrook or Pilgrim. The costs are average costs to fish hatcheries across North America to produce different species of fish for stocking (AFS, 1993). The second component of replacement cost is the transportation cost, which includes costs associated with vehicles, personnel, fuel, water, chemicals, containers, and nets. The AFS (1993) estimates these costs at approximately $1.13 per mile, but does not indicate how many fish (or how many pounds of fish) are transported for this price. Lacking relevant data, EPA did not include the transportation costs in this valuation approach.

Tables G4-19 and G4-20 also presents the computed values of the annual average forage replacement cost losses at the two facilities. The value of forage losses at Seabrook using the replacement cost method is $20 per year for impingement and $5,600 per year for entrainment. Forage losses at Pilgrim are valued at $90 per year for impingement and $30,900 per year for entrainment.

Table G4-19: Replacement Cost of Various Forage Fish Species at the Seabrook Facility.

Species	Hatchery Costs [a,b] ($/lb)	Annual Cost of Replacing Forage Losses ($2000)	
		Impingement	Entrainment
American sand lance	0.34	$1	$633
Fourbeard rockling	0.34	$0	$226
Grubby	0.34	$2	$346
Lumpfish	0.34	$2	$25
Northern pipefish	0.34	$1	$2
Radiated shanny	0.34	$0	$31
Rainbow smelt	0.34	$12	$94
Rock gunnel	0.34	$1	$4,181
Sculpin spp.	0.34	$1	$40
Total		$20	$5,580

[a] Values are from AFS (1993). These costs use the average value for all species listed in AFS (1993) since the species listed are not included in AFS (1993).

[b] These values were inflated to $2000 from $1989, but this could be imprecise for current fish rearing and stocking costs.
ThuJan1711:32:33MST2002;TableD:lossinselectedforagespecies;Plant:seabrook.90.98;type:IPathname:P:/Intake/Seabrook-
Pilgrim/Science/scode/seabrook/tables.output.90.98.no.mussel/TableD.forage.eco.ter.repl.seabrook.90.98.I.csv

Table G4-20: Replacement Cost of Various Forage Fish Species at the Pilgrim Facility.

Species	Hatchery Costs [a, b] ($/lb)	Annual Cost of Replacing Forage Losses ($2000)	
		Impingement	Entrainment
American sand lance	0.34	$0	$6,557
Fourbeard rockling	0.34	$0	$563
Grubby	0.34	$1	0
Lumpfish	0.34	$1	$5
Radiated shanny	0.34	$0	$348
Rainbow smelt	0.34	$85	$16,137
Rock gunnel	0.34	$0	$6,319
Sculpin spp.	0.34	$0	$1,010
Total		$88	$30,939

[a] Values are from AFS (1993). These costs use the average value for all species listed in AFS (1993) since the species listed are not included in AFS (1993).

[b] These values were inflated to $2000 from $1989, but this could be imprecise for current fish rearing and stocking costs. ThuJan1710;34:23MST2002;TableD:lossinselectedforagespecies;Plant:pilgrim.74.99;type:IPathname:P:/Intake/Seabrook-Pilgrim/Science/scode/pilgrim/tables.output.74.99.no.mussel/TableD.forage.eco.ter.repl.pilgrim.74.99.I.csv

G4-4.2 Production Foregone Value of Forage Fish

This approach considers the foregone production of commercial and recreational fishery species resulting from I&E of forage species based on estimates of trophic transfer efficiency, as discussed in Chapter A5 of Part A of this document. The economic valuation of forage losses is based on the dollar value of the foregone fishery yield resulting from these losses. Results for entrainment of forage species at Seabrook are presented in Table G4-21. Results for entrainment of forage species at Pilgrim are presented in Table G4-22. The values listed are obtained from converting the forage species into species that may be commercially or recreationally valued. The values range from $65,700 to $141,500 per year for entrainment at Seabrook. For Pilgrim, the values range from $25,400 to $33,300 per year for entrainment. Impingement values were negligible and thus are not discussed.

Note that the results using the production foregone approach indicate higher losses at Seabrook than at Pilgrim, even though the replacement cost approach yields the opposite finding. This reflects the differences in the approaches, wherein replacement costs reflect the number of fish lost, and the production foregone approach captures how the different mix of fish losses may alter recreational and commercial biomass.

Table G4-21: Mean Annual Value of Production Foregone of Fishery Species Resulting from Entrainment of Forage Species at Seabrook.

Species	Annual Loss in Production Foregone Value from Entrainment of Forage Species ($2000)	
	Low	High
Atlantic herring	$4	$7
Bluefish	$63,013	$137,347
Butterfish	$58	$112
Cod Atlantic	$331	$569
Cunner	$289	$347
Mackerel Atlantic	$39	$87
Menhaden Atlantic	$592	$1,035
Plaice American	$311	$544
Pollock	$0	$1
Rainbow smelt	$49	$111
Searobin	$266	$298
Tautog	$357	$518
Windowpane	$259	$388
Winter flounder	$122	$156
Total	$65,690	$141,520

Fri Feb 08 10:11:16 MST 2002 ; TableD: loss in selected forage species; Plant: seabrook.90.98 ; type: E Pathname:
P:/Intake/Seabrook-Pilgrim/Science/scode/seabrook/tables.output.90.98.no.mussel/TableD.forage.eco.ter.repl.seabrook.90.98.E.csv

Table G4-22: Mean Annual Value of Production Foregone of Fishery Species Resulting from Entrainment of Forage Species at Pilgrim

Species	Annual Loss in Production Foregone Value from Entrainment of Forage Species ($2000)	
	Low	High
Atlantic cod	$549	$944
Atlantic mackerel	$1,421	$3,202
Cunner	$564	$679
Herring Atlantic	$568	$993
Menhaden Atlantic	$229	$401
Plaice American	$2,287	$4,003
Pollock	$161	$281
Rainbow smelt	$80	$181
Searobin	$15,895	$17,847
Silverside Atlantic	$16	$29
Tautog	$646	$936
Windowpane	$2	$4
Winter flounder	$2,968	$3,790
Total	$25,387	$33,288

Thu Feb 07 17:19:35 MST 2002 ; TableD: loss in selected forage species; Plant: pilgrim.74.99 ; type: E Pathname:
P:/Intake/Seabrook-Pilgrim/Science/scode/pilgrim/tables.output.74.99.no.mussel/TableD.forage.eco.ter.repl.pilgrim.74.99.E.csv

G4-5 Nonuse Values

Recreational consumer surplus and commercial impacts are only part of the total losses that the public realizes from I&E impacts on fisheries. Nonuse or passive use impacts arise when individuals value environmental changes apart from any past, present, or anticipated future use of the resource in question. Such passive use values have been categorized in several ways in the economic literature, typically embracing the concepts of existence (stewardship) and bequest (intergenerational equity) motives. Using a "rule of thumb" that nonuse impacts are at least equivalent to 50 percent of the recreational use impact (see Chapter A9 in Part A of this document for further discussion), EPA estimated nonuse values for baseline losses at Seabrook, to range from $500 to $600 per year for impingement and from $37,500 to $43,600 per year for entrainment. At Pilgrim, nonuse values for baseline losses range from $700 to $1,100 per year for impingement and from $143,900 to $204,400 per year for entrainment.

G4-6 Summary of Mean Annual Economic Value of I&E at Seabrook and Pilgrim

Tables G4-23 and G4-24 summarize the economic values associated with mean annual I&E at the Seabrook and Pilgrim facilities. Total impacts at Seabrook range from $3,400 to $5,100 per year for impingement and from $139,100 to $309,100 per year for entrainment. Total impacts at Pilgrim range from $3,200 to $4,900 per year for impingement and from $513,200 to $744,400 per year for entrainment.

Table G4-23: Summary of Economic Valuation of Mean Annual I&E at Seabrook Facility ($2000).		Impingement	Entrainment	Total
Commercial: Total Surplus (Direct Use, Market)	Low	$1,778	$20,985	$22,763
	High	$3,112	$36,724	$39,836
Recreational (Direct Use, Nonmarket)	Low	$1,083	$75,036	$76,119
	High	$1,295	$87,209	$88,504
Nonuse (Passive Use, Nonmarket)	Low	$542	$37,518	$38,060
	High	$647	$43,605	$44,252
Forage (Indirect Use, Nonmarket)				
Production Foregone	Low	NA	$65,690	$65,690
	High	NA	$141,520	$141,520
Replacement		$20	$5,580	$5,600
Total (Com + Rec + Nonuse + Forage)[a]	Low	$3,423	$139,119	$142,542
	High	$5,074	$309,058	$314,131

[a] In calculating the total low values, the lower of the two forage valuation methods (production foregone and replacement) was used and to calculate the total high values, the higher of the two forage valuation methods was used.
NA= Not included because values negligible.
Fri Feb 08 10:11:18 MST 2002 ; TableE.summary; Plant: seabrook.90.98 ; Pathname:
P:/Intake/Seabrook-Pilgrim/Science/scode/seabrook/tables.output.90.98.no.mussel/TableE.summary.seabrook.90.98.csv

Table G4-24: Summary of Economic Valuation of Mean Annual I&E at Pilgrim Facility ($2000).

		Impingement	Entrainment	Total
Commercial: Total Surplus (Direct Use, Market)	Low	$940	$55,976	$56,916
	High	$1,646	$97,958	$99,603
Recreational (Direct Use, Nonmarket)	Low	$1,499	$287,897	$289,396
	High	$2,115	$408,755	$410,869
Nonuse (Passive Use, Nonmarket)	Low	$749	$143,949	$144,698
	High	$1,057	$204,377	$205,435
Forage (Indirect Use, Nonmarket)				
Production Foregone	Low	NA	$25,387	$25,403
	High	NA	$33,288	$33,314
Replacement		$88	$30,939	$31,027
Total (Com + Rec + Nonuse + Forage)[a]	Low	$3,276	$513,209	$516,485
	High	$4,905	$744,377	$749,283

[a] In calculating the total low values, the lower of the two forage valuation methods (production foregone and replacement) was used and to calculate the total high values, the higher of the two forage valuation methods was used.
NA= Not included because values negligible.
Thu Feb 07 17:19:36 MST 2002 ; TableE.summary; Plant: pilgrim.74.99 ; Pathname: P:/Intake/Seabrook-Pilgrim/Science/scode/pilgrim/tables.output.74.99.no.mussel/TableE.summary.pilgrim.74.99.csv
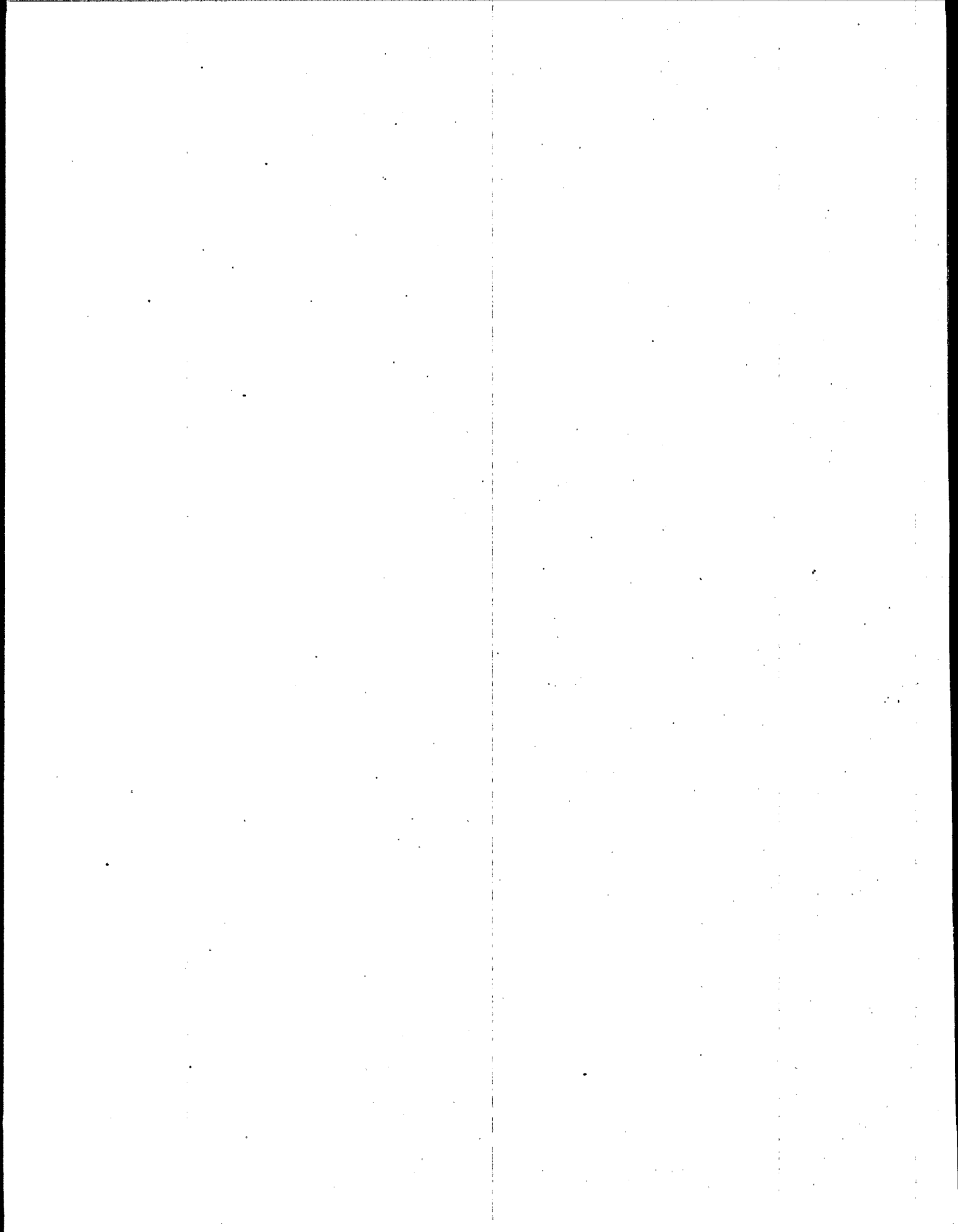
Chapter G5: HRC Valuation of I&E Losses at the Pilgrim Facility

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.

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
Scarobin	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)
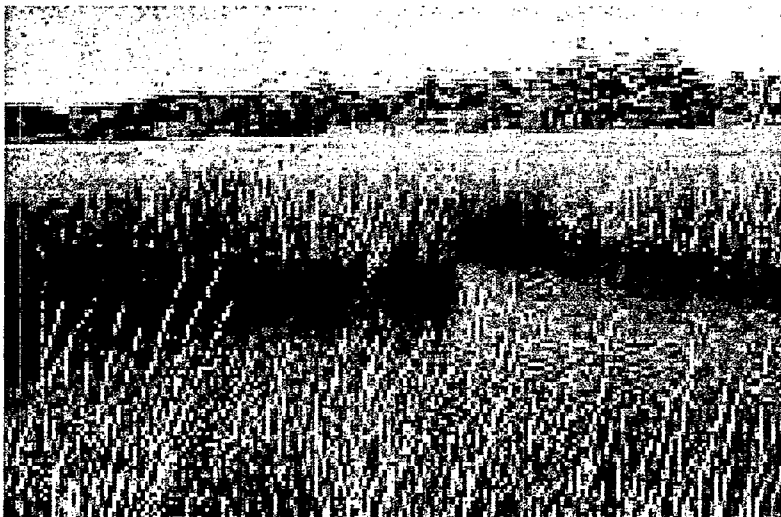
Create artificial reefs

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
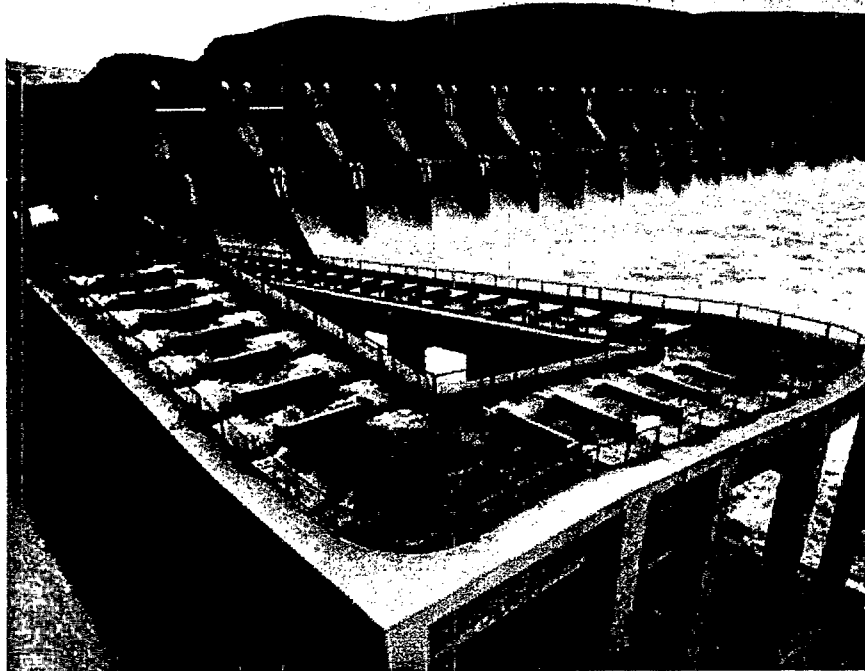
Source: Pollock, 2001.

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 m² 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 m² 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 m²)[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 m² and shoot biomass (wet) > 100 g/m². 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 m² 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 m² 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 m² 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 m² and shoot biomass (wet) > 100 g/m². 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 m² of SAV habitat.

Heck et al. (1989) also report that the dry weight of the SAV shoots is over 180 g/m² 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/m² 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 m²)[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 m² and shoot biomass (wet) > 100 g/m².
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 m² 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 m² 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 m²)		
		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 m² 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 m²)		
		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 m²)		
		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 m² 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 m² 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 65-19: 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 m² 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 m² 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 m² 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 m² 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 m² 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 m² 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 (m²)	Year	Adult Cunner Population Estimate		Assumed Adult Cunner Density Estimates (fish/m²)	
			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/m² reef)	Sampling Efficiency Adjustment Factor	Life Stage Adjustment Factor	Restored vs. Undisturbed Habitat Adjustment Factor	Expected Age 1 Increased Production (fish per m² 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 m² of Revegetated Substrate (rounded)	Number of 100 m² 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 m² of Restored Tidal Wetland (rounded)	Number of m² 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 m² of Artificial Reef (rounded)	Number of m² 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 m² 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 m² 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 m² of habitat being revegetated, this provides an average unit cost of $1,940 per m². 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 m²). The costs of identifying and evaluating the suitability of potential restoration sites were set at 1 percent ($19 per m²). 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 m², 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 m² TERFS / 4,047 m² per acre) and 1:34 (120 1 m² TERFS / 4,047 m² 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 m² of SAV Restored	Cost per 100 m² 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

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[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 m² restored habitat			$787
Annualized monitoring cost per 100 m² 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 m² 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 65-35: 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		Required Units of Restoration Implementation[a]	Units of Measure for Preferred Restoration Alternative	Total Annualized Unit Cost	Total Annualized Cost
	Species	Average Annual I&E Loss of Age 1 Equivalents				
Restore SAV	Northern pipefish	118	47	100 m² 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	m² 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	m² 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.

Preferred Restoration Alternative	Species Benefitting from the Restoration Alternative		Required Units of Restoration Implementation[a]	Units of Measure for Preferred Restoration Alternative	Total Annualized Unit Cost	Total Annualized Cost
	Species	Average Annual Impingement Loss of Age 1 Equivalents				
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

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

[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		Required Units of Restoration Implementation[a]	Units of Measure for Preferred Restoration Alternative	Total Annualized Unit Cost	Total Annualized Cost
	Species	Average Annual Entrainment Loss of Age 1 Equivalents				
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)

1. Age-1 equivalents losses per year
  I: 53.000 fish
  E: 14 million fish plus 160 billion mussels

2. Tidal wetland restoration costs
  I: Atlantic silverside $219k/yr
  E: winter flounder $4.7M/yr
  I&E: winter flounder $4.7M/yr

2. SAV costs
  I: northern pipefish $58k/yr
  E: northern pipefish unvalued
  I&E: northern pipefish $58k/yr

2. Artificial reef costs
  I: tautog $170k/yr
  E: cunner $4.4M/yr
  I&E: cunner $4.4M/yr

2. Fish passage costs
  I: alewife $49k/yr
  E: alewife unvalued
  I&E: alewife $49k/yr

2. Species for which HRC values not calculated
  I: 14 fish and 1 mussel species unvalued (16,600 lost per year)
  E: 14 fish and 1 mussel species unvalued (160 billion lost per year)
  I&E: 14 fish and 1 mussel species unvalued (160 billion lost per year)

3. Total HRC (tidal wetlands + SAV + artificial reefs + fish passage)
  I: $0.5M/yr
  E: $9.1M/yr
  I&E: $9.2M/yr

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.

Chapter G6: Benefits Analysis for the Seabrook and Pilgrim Facilities

This chapter presents the results of EPA's evaluation of the economic benefits associated with reductions in I&E at the Seabrook and Pilgrim facilities. The economic benefits that are reported here are based on the values presented in Chapter G4 and EPA's estimates of current I&E at these facilities (discussed in Chapter G3). Section G6-1 presents a summary of I&E losses and associated economic values. Section G6-2 presents economic losses at Pilgrim expressed in terms of habitat replacement costs (HRC), as discussed in Chapter G5. Section G6-3 discusses potential benefits of reductions in I&E based on both the benefits transfer approach presented in Chapter G4

and the HRC approach presented in Chapter G5. Section G6-4 discusses the uncertainties in the benefits analysis.

G6-1 OVERVIEW OF I&E AND ASSOCIATED ECONOMIC VALUES

The flowchart in Figure G6-1 summarizes how economic values of I&E losses at Seabrook were derived from the I&E estimates discussed in Chapter G3. Figures G6-2 and G6-3 indicate the distribution of Seabrook's I&E losses by species category and associated economic values. Figures G6-4 through G6-6 present this information for the Pilgrim facility. These diagrams reflect baseline losses based on current technology. All dollar values and percentages of losses reflect midpoints of the ranges for the categories of commercial, recreational, nonuse, and forage values.

Figure G6-1: Overview and Summary of Average Annual I&E at the Seabrook Facility and Associated Economic Values (based on current configuration; all results are annualized)[c]

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1. Number of organisms lost (eggs, larvae, juveniles, etc.)[b]
  I: 10,000 organisms
  E: 831 million organisms

2. Age 1 equivalents lost (number of fish)[b]
  I: 13,100 fish (4,600 forage, 8,500 commercial and recreational)
  E: 4.5 million fish (4.2 million forage, 299,600 commercial and recreational)

3. Loss to fishery (recreational and commercial harvest)[b]
  I: 1,400 fish (1,800 lb)
  E: 32,700 fish (29,300 lb)

4. Value of Commercial losses
  I: 1,200 fish (1,500 lb)
      $2,400 (57.6% of $I loss)
  E: 15,300 fish (11,200 lb)
      $28,900 (12.9% of $E loss)

5. Value of Recreational losses
  I: 236 fish (290 lb)
      $1,200 (28.0% of $I loss)
  E: 17,500 fish (18,200 lb)
      $81,200 (36.2% of $E loss)

6. Value of Forage losses (valued using either replacement cost method or as production foregone to fishery yield)
  I: 4,600 fish
      $20 (0.4% of $I loss)
  E: 4.2 million fish
      $73,600 (32.8% of $E loss)

7. Nonuse Values
  I: $600 (14.0% of $I loss)
  E: $40,600 (18.1% of $E loss)

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[a] All dollar values are the midpoint of the range of estimates.
[b] From Tables G4-2, G4-4, G4-15 and G4-16 of Chapter G4.
Note: Species with I&E <1% of the total I&E were not valued.

Figure G6-2: Seabrook: Distribution of Impingement Losses by Species Category

35.1% Forage Fish[a]
UNDERVALUED (valued
using replacement cost
method or as production
foregone to fishery yield)
[0.4% of $I] [b]

54.2% Commercial and
Recreational Fish[a]
UNVALUED (i.e.,
unharvested)
[0% of $I]

10.7% Commercial and
Recreational Fish[a]
VALUED (as direct loss to
fishery; commercial losses are
9.2% of total)
[85.6% of $I] [b]

Total: 13,100 fish per year (age 1 equivalents)[a]
Total impingement value = $4,200[b]

[a] Impacts shown are to age 1 equivalent fish, except impacts to the commercially and recreationally harvested fish include impacts for all ages vulnerable to the fishery.
[b] Midpoint of estimated range. Nonuse values are 14.0% of total estimated $I loss.

Figure G6-3: Seabrook: Distribution of Entrainment Losses by Species Category

0.7% Commercial and
Recreational Fish[a]
VALUED (as direct loss to
fishery; commercial losses are
0.3% of total)
[49.1% of $E] [b]

5.9% Commercial and
Recreational Fish[a]
UNVALUED (i.e.,
unharvested)
[0% of $E] [b]

93.4% Forage Fish[a]
UNDERVALUED (valued
using replacement cost
method or as production
foregone to fishery yield)
[32.8% of $E] [b]

Total: 4.5 million fish per year (age 1 equivalents)[a]
Total entrainment value = $224,100[b]

[a] Impacts shown are to age 1 equivalent fish, except impacts to the commercially and recreationally harvested fish include impacts for all ages vulnerable to the fishery.
[b] Midpoint of estimated range. Nonuse values are 18.1% of total estimated $E loss.

Figure G6-4: Overview and Summary of Average Annual I&E at the Pilgrim Facility and Associated Economic Values (based on current configuration; all results are annualized)[a]

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┌─────────────────────────────────────────────────────────────┐
│ 1. Number of organisms lost (eggs, larvae, juveniles, etc.)[b]│
│    I:  37,300 organisms                                       │
│    E:  4.40 billion organisms                                 │
└─────────────────────────────────────────────────────────────┘
                              │
                              ▼
┌─────────────────────────────────────────────────────────────┐
│ 2. Age 1 equivalents lost (number of fish)[b]                 │
│    I:  52,800 fish (1,600 forage, 51,200 commercial and recreational)│
│    E:  14.4 million fish (11.8 million forage, 2.6 million commercial and recreational)│
└─────────────────────────────────────────────────────────────┘
                              │
                              ▼
┌─────────────────────────────────────────────────────────────┐
│ 3. Loss to fishery (recreational and commercial harvest)[b]   │
│    I:  6,300 fish (4,300 lb)                                   │
│    E:  121,000 fish (91,100 lb)                               │
└─────────────────────────────────────────────────────────────┘
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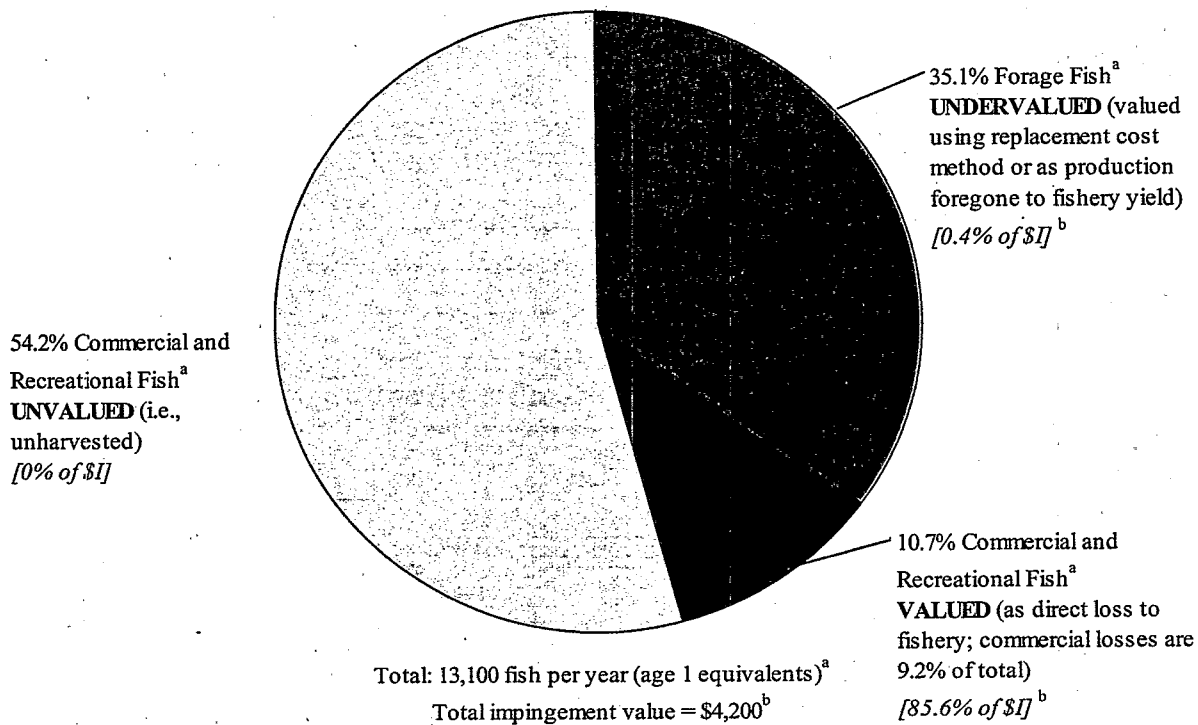
4. Value of Commercial losses
I: 5,900 fish (3,800 lb)
    $1,300 (31.9% of $I loss)
E: 47,300 fish (33,700 lb)
    $77,000 (12.2% of $E loss)

5. Value of Recreational losses
I: 371 fish (186 lb)
    $1,800 (44.6% of $I loss)
E: 73,600 fish (45,800 lb)
    $348,600 (55.4% of $E loss)

6. Value of Forage losses
(valued using either replacement cost method or as production foregone to fishery yield)
I: 1,600 fish
    $90 (1.3% of $I loss)
E: 11.2 million fish
    $29,300 (4.7% of $E loss)

7. Nonuse Values
I: $900 (22.3% of $I loss)
E: $174,300 (27.7% of $E loss)

8. Habitat replacement cost
I: $840,000 per year
E: $12.3 million per year

[a] All dollar values are the midpoint of the range of estimates.
[b] From Tables G4-3, G4-5, G4-17, and G4-18 of Chapter G4.
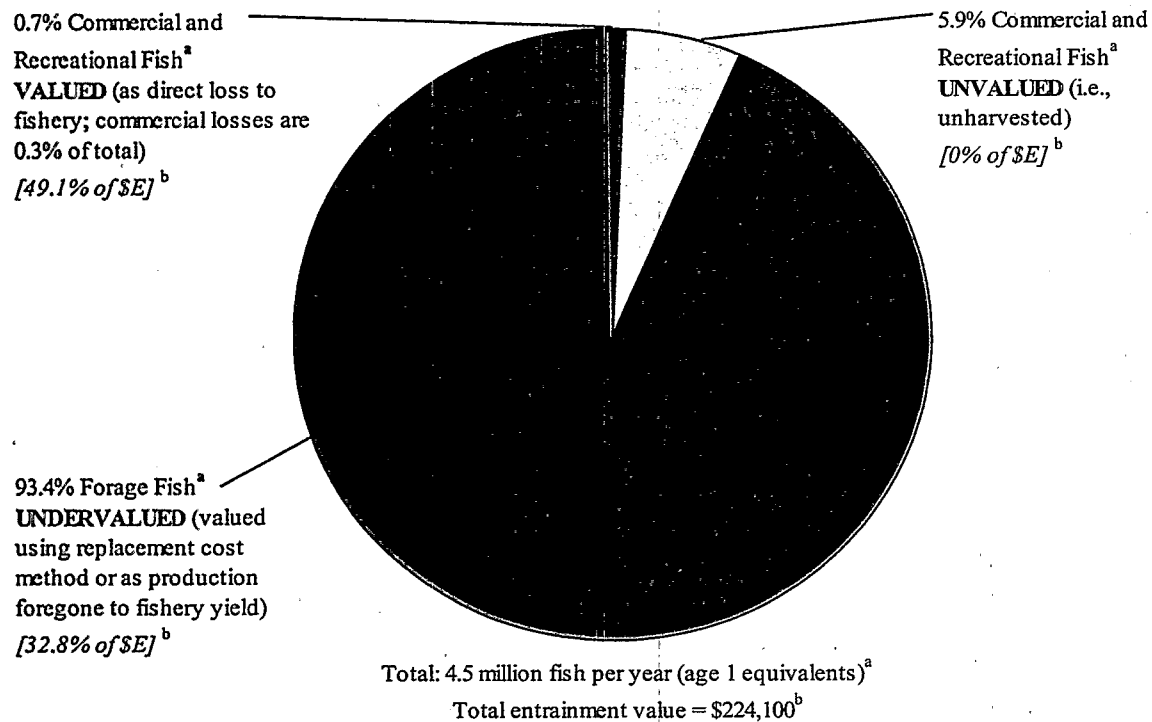Note: Species with I&E <1% of the total I&E were not valued.

Figure G6-5: Pilgrim: Distribution of Impingement Losses by Species Category and Associated Economic Values
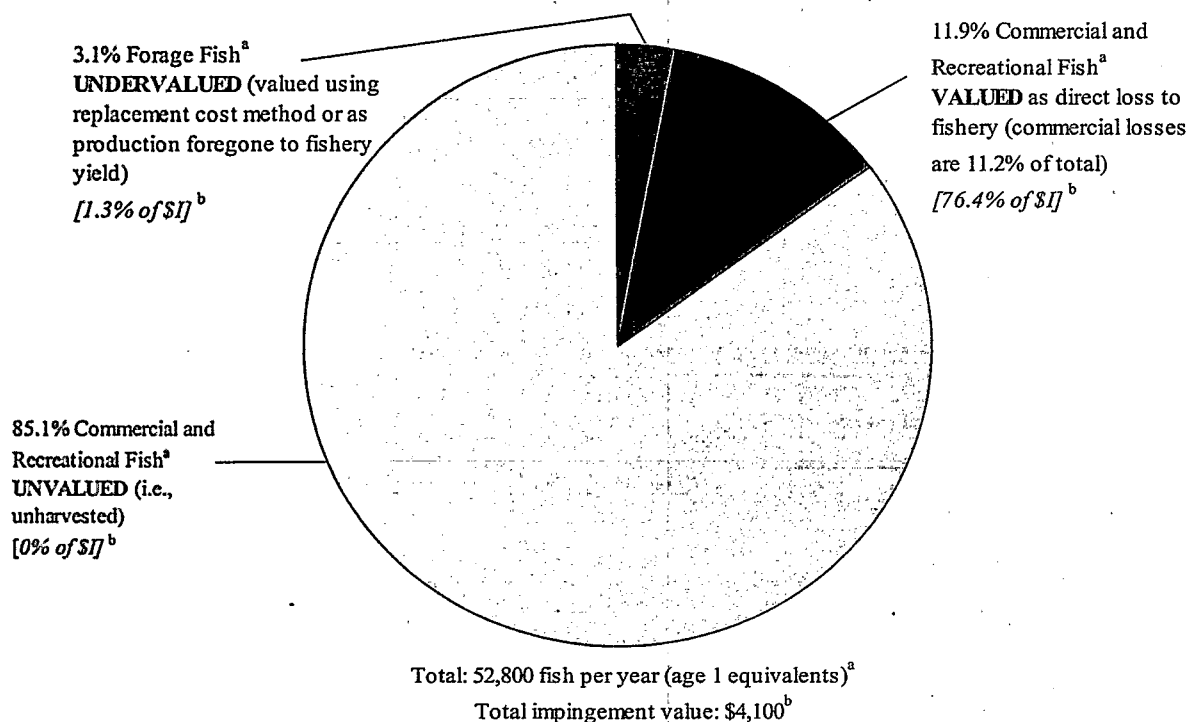
3.1% Forage Fish[a]
UNDERVALUED (valued using replacement cost method or as production foregone to fishery yield)
[1.3% of $I] [b]

11.9% Commercial and Recreational Fish[a]
VALUED as direct loss to fishery (commercial losses are 11.2% of total)
[76.4% of $I] [b]

85.1% Commercial and Recreational Fish[a]
UNVALUED (i.e., unharvested)
[0% of $I] [b]

Total: 52,800 fish per year (age 1 equivalents)[a]
Total impingement value: $4,100[b]

[a] Impacts shown are to age 1 equivalent fish, except impacts to the commercially and recreationally harvested fish include impacts for all ages vulnerable to the fishery.
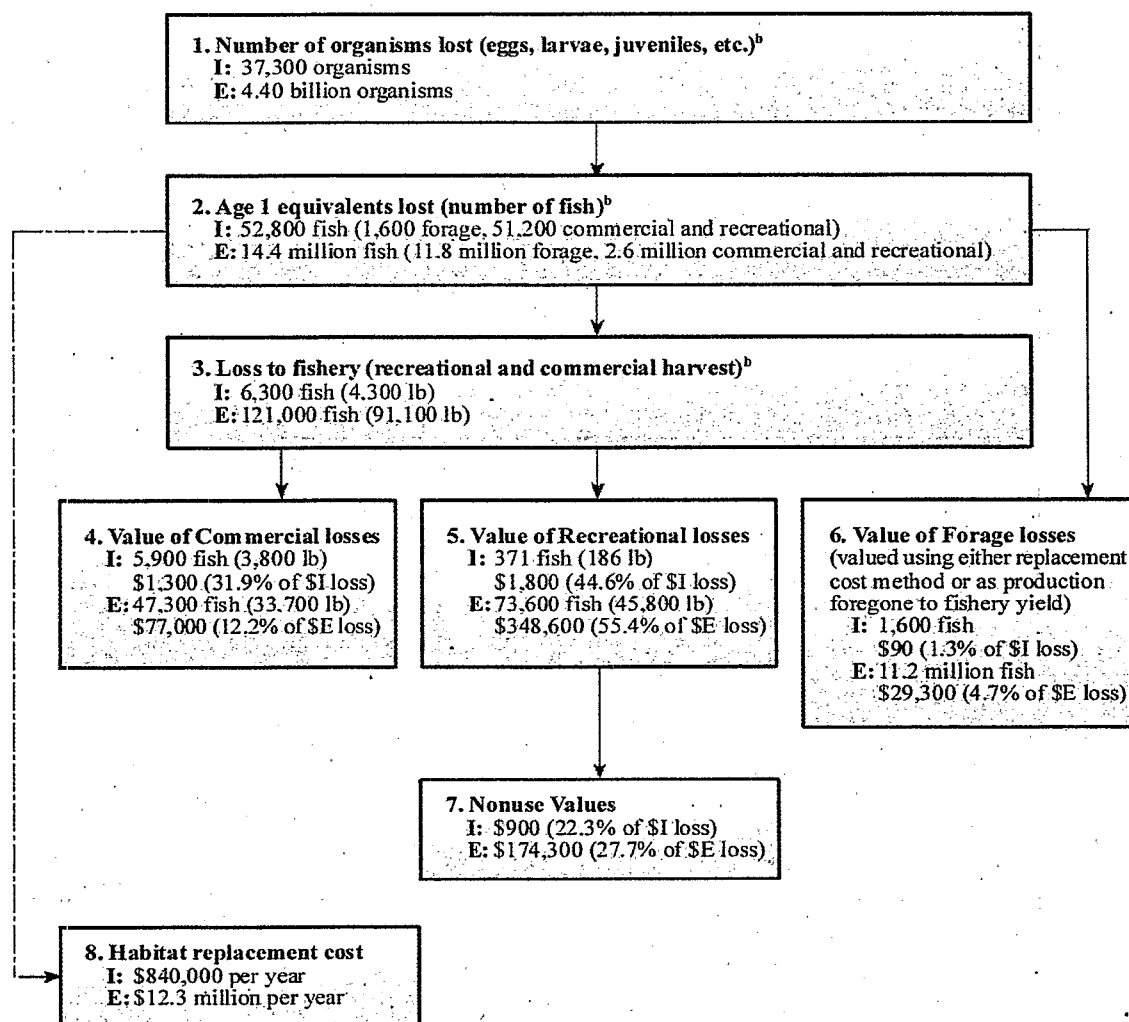[b] Midpoint of estimated range. Nonuse values are 22.3% of total estimated $I loss.

Figure G6-6: Pilgrim: Distribution of Entrainment Losses by Species Category and Associated Economic Values
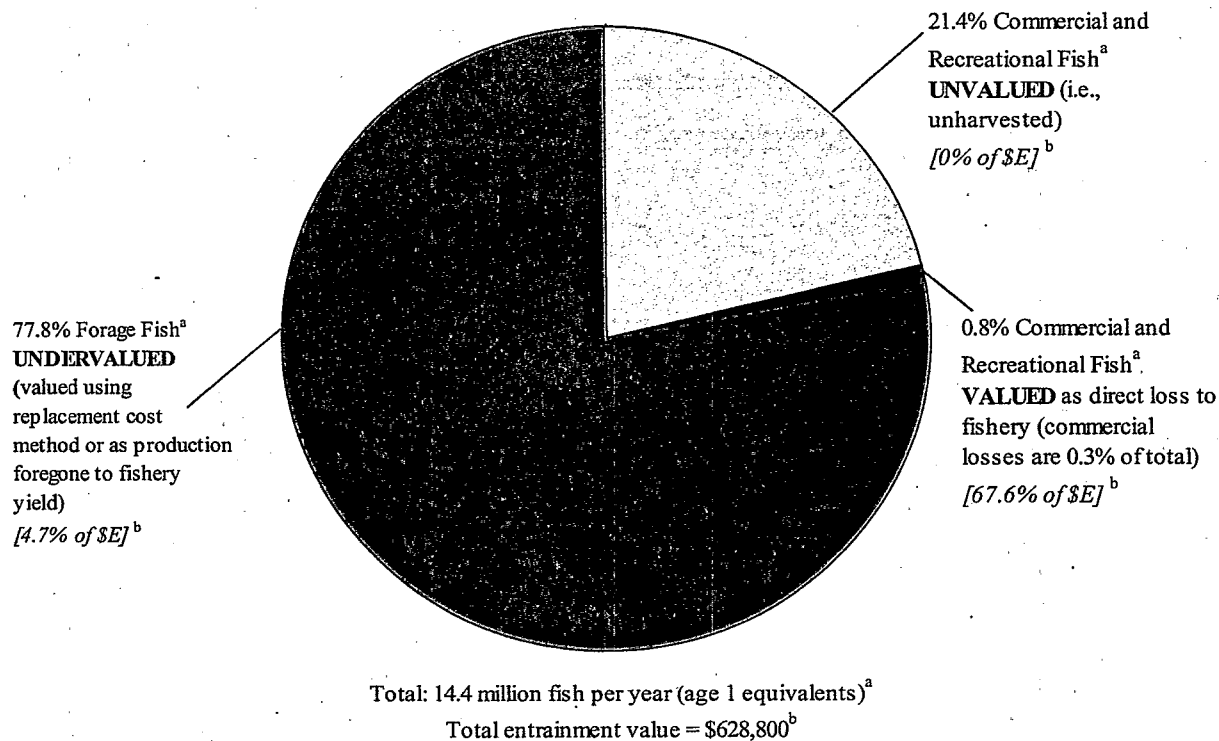
77.8% Forage Fish[a]
UNDERVALUED
(valued using
replacement cost
method or as production
foregone to fishery
yield)
[4.7% of $E] [b]

21.4% Commercial and
Recreational Fish[a]
UNVALUED (i.e.,
unharvested)
[0% of $E] [b]

0.8% Commercial and
Recreational Fish[a].
VALUED as direct loss to
fishery (commercial
losses are 0.3% of total)
[67.6% of $E] [b]

Total: 14.4 million fish per year (age 1 equivalents)[a]
Total entrainment value = $628,800[b]

[a] Impacts shown are to age 1 equivalent fish, except impacts to the commercially and recreationally harvested fish include impacts to all ages vulnerable to the fishery.
[b] Midpoint of estimated range. Nonuse values are 27.7% of total estimated $E loss.

G6-2 BASELINE LOSSES USING HRC METHOD

Chapter G5 presented baseline economic losses using the HRC approach. Baseline losses for I&E are $0.5 million and $9.1 million per year, respectively, for Pilgrim. These HRC values were used as an upper bound of I&E losses, while the midpoint of the benefits transfer values were used as a lower bound. The HRC approach was not applied to I&E for Seabrook.

G6-3 ANTICIPATED ECONOMIC BENEFITS OF REDUCED I&E FROM VARIOUS TECHNOLOGIES

Tables G6-1 and G6-2 show the estimated economic benefits of various I&E reductions at the Seabrook and Pilgrim facilities, respectively. The benefits of reducing I&E at Seabrook are expected to range from $2,000 to $3,000 per year for a 60% reduction in impingement and from $97,000 to $216,000 per year for a 70% reduction in entrainment. The benefits of reducing I&E at Pilgrim are expected to range from $2,000 to $298,000 per year for a 60% reduction in impingement and from $440,000 to over $6.4 million per year for a 70% reduction in entrainment.

Note that the results derived for Pilgrim reflect loss estimates derived from an HRC analysis; similar HRC findings are not available for Seabrook. This is a key reason why the Pilgrim losses are much higher than the Seabrook estimates, at the upper end of the range.

Table G6-1: Summary of Current Economic Losses and Benefits of a Range of Potential I&E Reductions at Seabrook Facility ($2000)

		Impingement	Entrainment	Total
Baseline losses	low	$3,000	$139,000	$142,000
	high	$5,000	$309,000	$314,000
Benefits of 10% reductions	low	$0	$14,000	$14,000
	high	$1,000	$31,000	$31,000
Benefits of 20% reductions	low	$1,000	$28,000	$28,000
	high	$1,000	$62,000	$63,000
Benefits of 30% reductions	low	$1,000	$42,000	$43,000
	high	$2,000	$93,000	$94,000
Benefits of 40% reductions	low	$1,000	$56,000	$57,000
	high	$2,000	$124,000	$126,000
Benefits of 50% reductions	low	$2,000	$70,000	$71,000
	high	$3,000	$155,000	$157,000
Benefits of 60% reductions	low	$2,000	$83,000	$85,000
	high	$3,000	$185,000	$188,000
Benefits of 70% reductions	low	$2,000	$97,000	$99,000
	high	$4,000	$216,000	$220,000
Benefits of 80% reductions	low	$2,000	$111,000	$114,000
	high	$4,000	$247,000	$251,000
Benefits of 90% reductions	low	$3,000	$125,000	$128,000
	high	$5,000	$278,000	$283,000

Table G6-2: Summary of Current Economic Losses and Benefits of a Range of Potential I&E Reductions at Pilgrim Facility ($2000)

		Impingement	Entrainment	Total
Baseline losses	low	$4,000	$629,000	$633,000
	high	$497,000	$9,097,000	$9,594,000
Benefits of 10% reductions	low	$0	$63,000	$63,000
	high	$50,000	$910,000	$959,000
Benefits of 20% reductions	low	$1,000	$126,000	$127,000
	high	$99,000	$1,819,000	$1,919,000
Benefits of 30% reductions	low	$1,000	$189,000	$190,000
	high	$149,000	$2,729,000	$2,878,000
Benefits of 40% reductions	low	$2,000	$252,000	$253,000
	high	$199,000	$3,639,000	$3,837,000
Benefits of 50% reductions	low	$2,000	$315,000	$317,000
	high	$248,000	$4,548,000	$4,797,000
Benefits of 60% reductions	low	$2,000	$377,000	$380,000
	high	$298,000	$5,458,000	$5,756,000
Benefits of 70% reductions	low	$3,000	$440,000	$443,000
	high	$348,000	$6,368,000	$6,716,000
Benefits of 80% reductions	low	$3,000	$503,000	$506,000
	high	$397,000	$7,277,000	$7,675,000
Benefits of 90% reductions	low	$4,000	$566,000	$570,000
	high	$447,000	$8,187,000	$8,634,000

G6-4 SUMMARY OF OMISSIONS, BIASES, AND UNCERTAINTIES IN THE BENEFITS ANALYSIS

Table G6-3 presents an overview of omissions, biases, and uncertainties in the benefits estimates. Factors with a negative impact on the benefits estimate bias the analysis downward, and therefore would raise the final estimate if they were properly accounted.

Table G6-3: Omissions, Biases, and Uncertainties in the Benefits Estimates

Issue	Impact on Benefits Estimate	Comments
Long-term fish stock affects not considered	Understates benefits[a]	EPA assumed that the effects on stocks are the same each year, and that the higher fish kills would not have cumulatively greater impact.
Effect of interaction with other environmental stressors	Understates benefits[a]	EPA did not analyze how the yearly reductions in fish may make the stock more vulnerable to other environmental stressors. In addition, as water quality improves over time due to other watershed activities, the number of fish impacted by I&E may increase.
Recreation participation is held constant[a]	Understates benefits[a]	Recreational benefits only reflect anticipated increase in value per activity outing; increased levels of participation are omitted.
Boating, bird-watching, and other in-stream or near-water activities are omitted[a]	Understates benefits[a]	The only impact to recreation considered is fishing.
HRC does not cover losses for all species	Understates benefits[a]	As a result of the HRC method, species with losses that are not addressed can only increase the HRC total valuation
Nonuse benefits	Uncertain	EPA assumed that nonuse benefits are 50 percent of recreational angling benefits
Effect of change in stocks on number of landings	Uncertain	EPA assumed a linear stock to harvest relationship, that a 13 percent change in stock would have a 13 percent change in landings; this may be low or high, depending on the condition of the stocks.
Recreation values for various geographic areas	Uncertain	The recreational values used are from various regions and are not from New England in particular.

[a] Benefits would be greater than estimated if this factor were considered.

Chapter G7:

Conclusions

As indicated in Chapter G4, average impingement losses at Seabrook are valued at between $3,000 and $5,000 per year, and . average entrainment losses are valued at between $139,000 and $309,000 per year (all in $2000). Average impingement losses at Pilgrim are valued at between $3,000 and $5,000 per year, and average entrainment losses are valued at between $513,000 and $744,000 per year (all in $2000). These values reflect estimates derived using benefits transfer.

Benefits estimates were based on percentage reductions in estimated current I&E at Seabrook and Pilgrim (Chapter G6). EPA also developed an HRC analysis to value I&E losses at Pilgrim (Chapter G5). Using the HRC approach, the value of I&E losses at Pilgrim are approximately $497,000 for impingement, and over $19.1 million per year for entrainment (HRC annualized at 7 percent over 20 years). These HRC estimates were merged with the benefits transfer results (from Chapter G4) to develop a more comprehensive range of loss estimates for the Pilgrim facility. HRC results were used as an upper bound, while the midpoints of benefits transfer estimates were used as a lower bound. On this basis, EPA estimates potential annual benefits of reduced I&E at Pilgrim ranging from $2,000 to $298,000 per year for a 60% reduction in impingement, and from $440,000 to $6.4 million for a 70% reduction in entrainment. The annual benefits of reduced I&E at Seabrook are estimated to range from $2,000 to $3,000 for a 60% reduction in impingement and from $97,000 to $216,000 for a 70% reduction in entrainment.

In interpreting these results, it is important to consider several critical caveats and limitations of EPA's analysis. These caveats have been detailed in preceding chapters. EPA included forage species impacts in the economic benefits calculations, but because techniques for valuing such losses are limited, the final estimates may well underestimate the full ecological and economic value of these losses. Thus, on the whole, EPA believes the estimates developed here underestimate the economic benefits of reducing I&E at similar facilities.
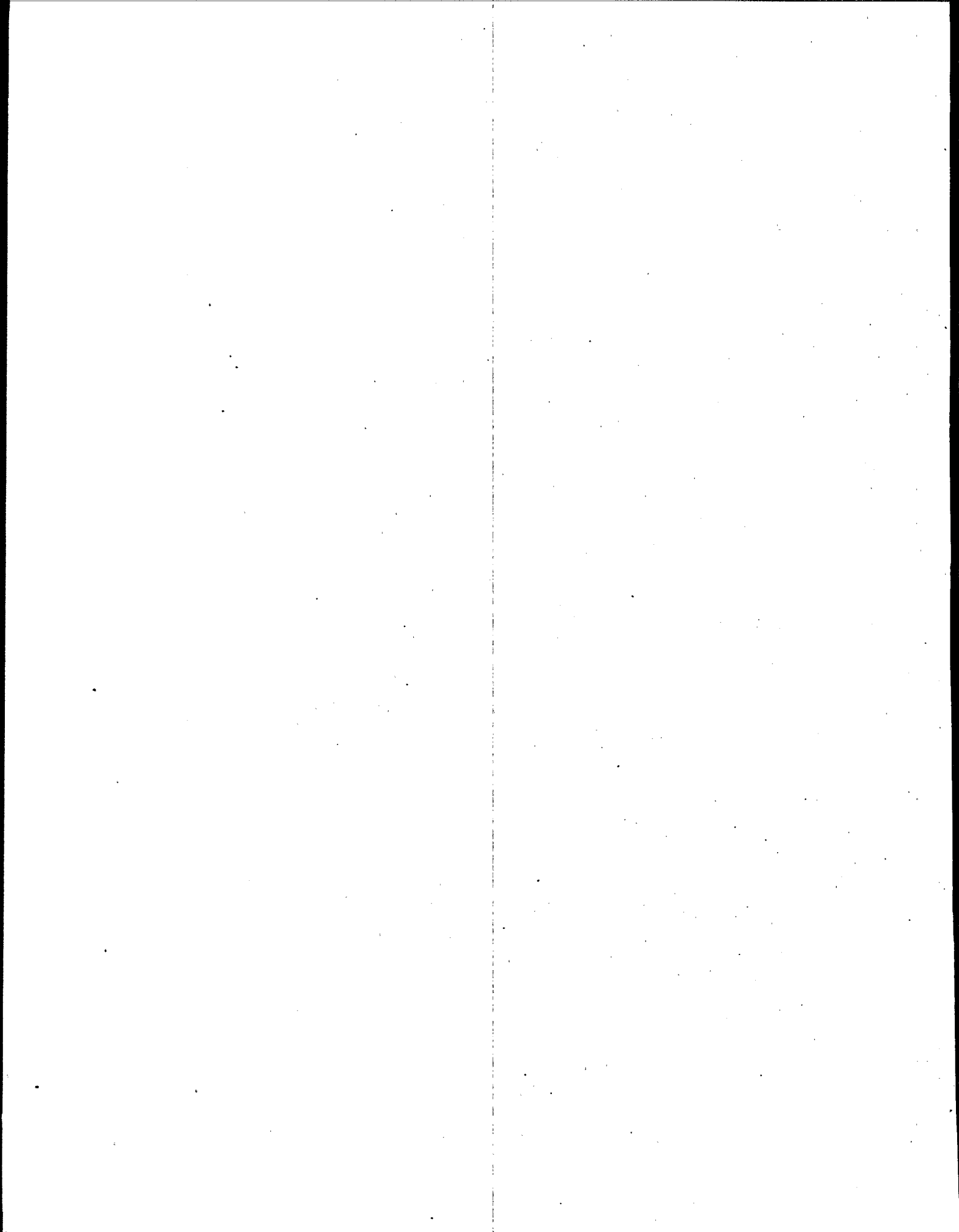
Appendix G1: Life History Parameter Values Used to Evaluate I&E

The tables in this appendix present the life history parameter values used by EPA to calculate age 1 equivalents, fishery yields, and production foregone from I&E data for the Seabrook and Pilgrim facilities. Life history data and fishing mortality rates were compiled from a variety of sources, with a focus on obtaining data on local stocks whenever possible.

Table G1-1: Alewife Species Parameters				
Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)[a]	Fraction Vulnerable to Fishery[a]	Weight (lb)
Eggs	0.9[a]	0	0	0.0022[c]
Larvae	5.75[a]	0	0	0.00661[c]
Juvenile 1	10.1[a]	0	0	0.022[c]
Age 1+	0.7[b]	0	0	0.0303[a]
Age 2+	0.7[b]	0	0	0.125[a]
Age 3+	0.7[b]	0	0	0.348[d]
Age 4+	0.7[b]	0.1	0.45	0.443[d]
Age 5+	0.7[b]	0.1	0.9	0.496[d]
Age 6+	0.7[b]	0.1	1	0.536[d]
Age 7+	0.7[b]	0.1	1	0.598[d]
Age 8+	0.7[b]	0.1	1	0.723[d]

[a] Based on alewife in the Delaware Estuary, as provided in PSEG, 1999c.
[b] Froese and Pauly, 2001.
[c] Assumed based on size (Able and Fahay, 1998).
[d] Scott and Scott, 1988.

Table G1-2: American Plaice Species Parameters				
Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)[d]	Fraction Vulnerable to Fishery[d]	Weight (lb)[e]
Eggs	2.3[a]	0	0	0.0000000111[f]
Larvae	9.13[b]	0	0	0.0000173[f]
Age 1+	0.2[c]	0	0	0.00537[g]
Age 2+	0.2[c]	0.32	0.5	0.0545[g]
Age 3+	0.2[c]	0.32	1	0.121[h]
Age 4+	0.2[c]	0.32	1	0.212[f]
Age 5+	0.2[c]	0.32	1	0.322[f]
Age 6+	0.2[c]	0.32	1	0.467[f]
Age 7+	0.2[c]	0.32	1	0.652[f]
Age 8+	0.2[c]	0.32	1	0.822[f]
Age 9+	0.2[c]	0.32	1	1.02[f]
Age 10+	0.2[c]	0.32	1	1.25[f]
Age 11+	0.2[c]	0.32	1	1.51[f]
Age 12+	0.2[c]	0.32	1	1.81[f]
Age 13+	0.2[c]	0.32	1	2.15[f]
Age 14+	0.2[c]	0.32	1	2.4[f]
Age 15+	0.2[c]	0.32	1	2.67[f]
Age 16+	0.2[c]	0.32	1	2.96[f]
Age 17+	0.2[c]	0.32	1	3.27[f]
Age 18+	0.2[c]	0.32	1	3.6[f]
Age 19+	0.2[c]	0.32	1	3.96[f]
Age 20+	0.2[c]	0.32	1	4.34[f]
Age 21+	0.2[c]	0.32	1	4.74[f]
Age 22+	0.2[c]	0.32	1	5.17[f]
Age 23+	0.2[c]	0.32	1	5.63[f]
Age 24+	0.2[c]	0.32	1	5.87[f]
Age 25+	0.2[c]	0.32	1	5.94[h]

[a] Calculated from survival (Stone & Webster Engineering Corporation, 1977) (Atlantic silverside) using the equation: (natural mortality) = -LN(survival) - (fishing mortality).
[b] Calculated from extrapolated survival using the equation: (natural mortality) = -LN(survival) - (fishing mortality).
[c] NOAA, 1993.
[d] O'Brien, 2000. Fraction vulnerable assumed based on size.
[e] Weight calculated from length using the formula: $(4.970 \times 10^{-7}) * \text{Length(mm)}^{3.345} = \text{weight(g)}$ (Froese and Pauly, 2001).
[f] Length from Scott and Scott (1988).
[g] Length assumed based on Scott and Scott (1988) and Shultz, 2001.
[h] Length from Shultz (2001).

Table G1-3: American Sand Lance Species Parameters

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)[d]	Fraction Vulnerable to Fishery[d]	Weight (lb)[e]
Eggs	2.3[a]	0	0	0.000000000353[f]
Larvae	4.19[b]	0	0	0.000485[f]
Age 1+	1[c]	0	0	0.00469[f]
Age 2+	1[c]	0	0	0.0313[f]
Age 3+	1[c]	0	0	0.0636[f]
Age 4+	1[c]	0	0	0.106[f]
Age 5+	1[c]	0	0	0.144[g]
Age 6+	1[c]	0	0	0.19[f]
Age 7+	1[c]	0	0	0.231[g]
Age 8+	1[c]	0	0	0.246[g]
Age 9+	1[c]	0	0	0.262[f]

[a] Calculated from survival (Stone & Webster Engineering Corporation, 1977) (Atlantic silverside) using the equation: (natural mortality) = -LN(survival) - (fishing mortality).

[b] Calculated from extrapolated survival using the equation: (natural mortality) = -LN(survival) - (fishing mortality).

[c] Froese and Pauly, 2001, Northern sand lance.

[d] Not a recreational or commercial species, thus no fishing mortality.

[e] Weight calculated from length using the formula: $(3.2 \times 10^{-7}) \ast \text{Length(mm)}^{3.491} = \text{weight(g)}$ (Froese and Pauly, 2001).

[f] Length from Scott and Scott (1988).

[g] Length assumed based on Scott and Scott (1988).

Table G1-4: Atlantic Cod Species Parameters

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)[d]	Fraction Vulnerable to Fishery[d]	Weight (lb)[e]
Eggs	4.87[a]	0	0	0.0000000974[f]
Larvae	6.75[b]	0	0	0.00000186[f]
Age 1+	0.4[c]	0	0	0.0225[g]
Age 2+	0.2[c]	0.29	0.5	0.245[g]
Age 3+	0.2[c]	0.29	1	0.628[g]
Age 4+	0.2[c]	0.29	1	1.29[g]
Age 5+	0.2[c]	0.29	1	2.45[g]
Age 6+	0.2[c]	0.29	1	3.33[g]

[a] Calculated from assumed survival using the equation: (natural mortality) = -LN(survival) - (fishing mortality).

[b] Calculated from extrapolated survival using the equation: (natural mortality) = -LN(survival) - (fishing mortality).

[c] Entergy Nuclear Generation Company, 2000.

[d] NOAA, 2001c.

[e] Weight calculated from length using the formula: $(8.85 \times 10^{-6}) \ast \text{Length(mm)}^{3.031} = \text{weight(g)}$ (Froese and Pauly, 2001).

[f] Length from Froese and Pauly (2001).

[g] Length from Scott and Scott (1988).

Table G1-5: Atlantic Herring Species Parameters				
Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)[b]	Fraction Vulnerable to Fishery[c]	Weight (lb)[d]
Eggs	3.36[a]	0	0	0.0000000170[e]
Larvae	6.53[a]	0	0	0.000222[f]
Age 1+	0.2[b]	0.28	0.5	0.0243[g]
Age 2+	0.2[b]	0.28	1	0.158[h]
Age 3+	0.2[b]	0.28	1	0.291[h]
Age 4+	0.2[b]	0.28	1	0.42[h]
Age 5+	0.2[b]	0.28	1	0.467[h]
Age 6+	0.2[b]	0.28	1	0.535[h]
Age 7+	0.2[b]	0.28	1	0.607[h]
Age 8+	0.2[b]	0.28	1	0.668[h]
Age 9+	0.2[b]	0.28	1	0.734[h]
Age 10+	0.2[b]	0.28	1	0.716[h]
Age 11+	0.2[b]	0.28	1	0.812[h]
Age 12+	0.2[b]	0.28	1	0.907[h]
Age 13+	0.2[b]	0.28	1	0.915[i]
Age 14+	0.2[b]	0.28	1	0.924[i]
Age 15+	0.2[b]	0.28	1	0.932[i]
Age 16+	0.2[b]	0.28	1	0.941[i]

[a] Calculated from survival (Entergy Nuclear Generation Company, 2000) using the equation: (natural mortality) = -LN(survival) - (fishing mortality).
[b] NOAA, 2001c.
[c] Commercial species vulnerable to fishing mortality at age 1.
[d] Weight calculated from length using the formula: $(1.22 \times 10^{-6}) \ast Length(mm)^{3.328} = weight(g)$ (Froese and Pauly, 2001).
[e] Length from Froese and Pauly (2001).
[f] Length from Reid et al. (1999).
[g] Length from Atlantic States Marine Fisheries Commission (2001a).
[h] Length from Scott and Scott (1988).
[i] Length assumed based on Scott and Scott (1988).

Table G1-6: Atlantic Mackerel Species Parameters

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)[c]	Fraction Vulnerable to Fishery[d]	Weight (lb)[e]
Eggs	2.39[a]	0	0	0.0000000362[f]
Larvae	10.6[a]	0	0	0.0000008[g]
Age 1+	0.52[b]	0	0	0.309[h]
Age 2+	0.37[b]	0.25	0.5	0.51[h]
Age 3+	0.37[b]	0.25	1	0.639[h]
Age 4+	0.37[b]	0.25	1	0.752[h]
Age 5+	0.37[b]	0.25	1	0.825[h]
Age 6+	0.37[b]	0.25	1	0.918[h]
Age 7+	0.37[b]	0.25	1	1.02[h]
Age 8+	0.37[b]	0.25	1	1.1[h]
Age 9+	0.37[b]	0.25	1	1.13[i]
Age 10+	0.37[b]	0.25	1	1.15[h]
Age 11+	0.37[b]	0.25	1	1.22[h]
Age 12+	0.37[b]	0.25	1	1.22[h]
Age 13+	0.37[b]	0.25	1	1.22[h]
Age 14+	0.37[b]	0.25	1	1.22[h]

[a] Calculated from survival (Entergy Nuclear Generation Company, 2000) using the equation: (natural mortality) = -LN(survival) - (fishing mortality).

[b] Overholtz et al., 1991.

[c] NOAA, 2001c.

[d] Recreational and commercial species. Vulnerable to fishing mortality at age 2.

[e] Weight calculated from length using the formula: $(3.039 \times 10^{-6})*Length(mm)^{3.18} = weight(g)$ (Froese and Pauly, 2001). Atlantic cod.

[f] Length assumed based on Atlantic cod (Froese and Pauly, 2001).

[g] Length from Froese and Pauly (2001).

[h] Length from Scott and Scott (1988).

[i] Length assumed based on Scott and Scott (1988).

Table G1-7: Atlantic Menhaden Parameters

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)[c]	Fraction Vulnerable to Fishery[d]	Weight (lb)[e]
Eggs	2.08[a]	0	0	0.0000000602[f]
Larvae	8.56[a]	0	0	0.00000068[f]
Age 1+	0.45[b]	0	0	0.545[d]
Age 2+	0.45[b]	0.8	0.5	0.855[d]
Age 3+	0.45[b]	0.8	1	1.08[d]
Age 4+	0.45[b]	0.8	1	1.31[d]
Age 5+	0.45[b]	0.8	1	1.47[d]
Age 6+	0.45[b]	0.8	1	1.59[d]
Age 7+	0.45[b]	0.8	1	3.36[g]
Age 8+	0.45[b]	0.8	1	5.21[h]

[a] Calculated from survival (Entergy Nuclear Generation Company, 2000) using the equation: (natural mortality) = -LN(survival) - (fishing mortality).
[b] NOAA, 2001c.
[c] Ruppert et al., 1985.
[d] Durbin et al., 1983.
[e] Weight calculated from length using the formula: $(6.02 \times 10^{-6}) * \text{Length(mm)}^{3.216} = \text{weight(g)}$ (Froese and Pauly, 2001).
[f] Length from Able and Fahay (1998).
[g] Length assumed based on Durbin et al. (1983) and Scott and Scott (1988).
[h] Length from Scott and Scott (1988).

Table G1-8: Atlantic Silverside Species Parameters

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)[d]	Fraction Vulnerable to Fishery[e]	Weight (lb)[f]
Eggs	2.3[a]	0	0	0.0000000246[g]
Larvae	6.12[b]	0	0	0.000108[g]
Age 1+	2.1[c]	0.19	0.5	0.0101[h]
Age 2+	2.1[c]	0.19	1	0.0186[h]

[a] Calculated from survival (Stone & Webster Engineering Corporation, 1977) using the equation: (natural mortality) = -LN(survival) - (fishing mortality).
[b] Calculated from extrapolated survival using the equation: (natural mortality) = -LN(survival) - (fishing mortality).
[c] Froese and Pauly, 2001.
[d] NOAA, 2001c. Atlantic herring.
[e] Commercial species. Vulnerable to fishing mortality at age 1.
[f] Weight calculated from length using the formula: $(5.691 \times 10^{-6}) * \text{Length(mm)}^{3.023} = \text{weight(g)}$ (Froese and Pauly, 2001).
[g] Length from Able and Fahay (1998).
[h] Length from Scott and Scott (1988).

Table G1-9: Bay Anchovy Species Parameters

Stage Name	Natural Mortality (per stage)[a]	Fishing Mortality (per stage)[a]	Fraction Vulnerable to Fishery[a]	Weight (lb)
Eggs	1.04	0	0	0.000022[b]
Yolksac larvae	1.57	0	0	0.000551[b]
Post-yolksac larvae 1	2.11	0	0	0.00108[b]
Post-yolksac larvae 2	4.02	0	0	0.00161[b]
Juvenile 1	0.0822	0	0	0.00214[b]
Juvenile 2	0.0861	0	0	0.00267[b]
Juvenile 3	0.129	0	0	0.0032[b]
Juvenile 4	0.994	0	0	0.0037[b]
Age 1+	1.62	0	0	0.00381[a]
Age 2+	1.62	0	0	0.00496[a]
Age 3+	1.62	0	0	0.00505[a]

[a] PSEG, 1999c.
[b] Assumed based on PSEG, 1999c.

Table G1-10: Blue Mussel Species Parameters

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery[e]	Weight (lb)[f]
Eggs	2.3[a]	0[d]	0	0.00022
Larvae	4.61[b]	0[d]	0	0.0022
Age 1+	0.602[c]	0.602[c]	0.5	0.0662
Age 2+	0.602[c]	0.602[c]	1	0.0728
Age 3+	0.0555[c]	0.0555[c]	1	0.0794
Age 4+	0.0555[c]	0.0555[c]	1	0.0833
Age 5+	0.0555[c]	0.0555[c]	1	0.0838
Age 6+	0.0555[c]	0.0555[c]	1	0.084
Age 7+	0.0555[c]	0.0555[c]	1	0.0842
Age 8+	0.0555[c]	0.0555[c]	1	0.0843
Age 9+	0.0555[c]	0.0555[c]	1	0.0843
Age 10+	1.2[c]	1.2[c]	1	0.0843
Age 11+	1.2[c]	1.2[c]	1	0.0843
Age 12+	1.2[c]	1.2[c]	1	0.0843

[a] Calculated from assumed survival using the equation: (natural mortality) = -LN(survival) - (fishing mortality).
[b] Calculated from survival (Stone & Webster Engineering Corporation, 1977) using the equation: (natural mortality) = -LN(survival) - (fishing mortality).
[c] Calculated from survival (Author Unknown, 2001) using the equation: (natural mortality) = -LN(survival) - (fishing mortality). Assumed half of mortality was natural and half was fishing.
[d] Shaw et al., 1988.
[e] Commercial species. Vulnerable to fishing mortality at age 1.
[f] Newell, 1989.

Table G1-11: Blueback Herring Species Parameters

Stage Name	Natural Mortality (per stage)[a]	Fishing Mortality (per stage)[a]	Fraction Vulnerable to Fishery[a]	Weight (lb)
Eggs	0.558	0	0	0.000022[b]
Yolksac larvae	1.83	0	0	0.00321[b]
Post-yolksac larvae 1	1.74	0	0	0.0064[b]
Juvenile 1	3.13	0	0	0.00959[b]
Juvenile 2	3.13	0	0	0.0128[b]
Age 1+	0.3	0	0	0.016[a]
Age 2+	0.3	0	0	0.0905[a]
Age 3+	0.3	0	0	0.204[a]
Age 4+	0.9	0	0	0.318[a]
Age 5+	1.5	0	0	0.414[a]
Age 6+	1.5	0	0	0.488[a]
Age 7+	1.5	0	0	0.54[a]
Age 8+	1.5	0	0	0.576[a]

[a] PSEG, 1999c.
[b] Assumed based on PSEG, 1999c.

Table G1-12: Bluefish Species Parameters

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)[d]	Fraction Vulnerable to Fishery[e]	Weight (lb)[f]
Eggs	2.3[a]	0	0	0.0000000386[g]
Larvae	5.27[b]	0	0	0.00000333[g]
Juvenile 1	5.27[b]	0	0	0.000116[g]
Age 1+	0.35[c]	0.4	0.5	0.54[h]
Age 2+	0.35[c]	0.4	1	0.785[h]
Age 3+	0.35[c]	0.4	1	1.91[h]
Age 4+	0.35[c]	0.4	1	2.45[i]
Age 5+	0.35[c]	0.4	1	3.06[i]
Age 6+	0.35[c]	0.4	1	3.78[i]
Age 7+	0.35[c]	0.4	1	4.58[i]
Age 8+	0.35[c]	0.4	1	5.49[i]
Age 9+	0.35[c]	0.4	1	6.5[i]
Age 10+	0.35[c]	0.4	1	7.64[i]
Age 11+	0.35[c]	0.4	1	8.87[i]
Age 12+	0.35[c]	0.4	1	10.3[h]

[a] Calculated from survival (Stone & Webster Engineering Corporation, 1977) (Atlantic silverside) using the equation: (natural mortality) = -LN(survival) - (fishing mortality).
[b] Calculated from extrapolated survival using the equation: (natural mortality) = -LN(survival) - (fishing mortality).
[c] NOAA, 1993.
[d] NOAA, 2001c.
[e] Commercial and recreational species. Assumed to be vulnerable to fishing mortality at age 1.
[f] Weight calculated from length using the formula: $(1.749 \times 10^{-5}) \ast Length(mm)^{2.77} = weight(g)$ (Froese and Pauly, 2001).
[g] Length from Wang and Kernehan (1979).
[h] Length from Clayton et al. (1978).
[i] Length assumed based on Clayton et al. (1978).

Table G1-13: Butterfish Species Parameters

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)[d]	Fraction Vulnerable to Fishery[e]	Weight (lb)[f]
Eggs	2.3[a]	0	0	0.00000000248[g]
Larvae	8.13[b]	0	0	0.00000151[g]
Age 1+	0.4[c]	0.76	0.5	0.0272[h]
Age 2+	0.4[c]	0.76	1	0.0986[h]
Age 3+	0.4[c]	0.76	1	0.944[h]

[a] Calculated from assumed survival using the equation: (natural mortality) = -LN(survival) - (fishing mortality).
[b] Calculated from extrapolated survival using the equation: (natural mortality) = -LN(survival) - (fishing mortality).
[c] NOAA, 1993.
[d] NOAA, 2001c.
[e] Commercial and recreational species. Assumed to be vulnerable to fishing mortality at age 1.
[f] Weight calculated from length using the formula: $(3.6 \times 10^{-6}) \cdot Length(mm)^{3.26}$ = weight(g) (Froese and Pauly, 2001).
[g] Length from Able and Fahay (1998).
[h] Length from Scott and Scott (1988).

Table G1-14: Cunner Species Parameters

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)[c]	Fraction Vulnerable to Fishery[c]	Weight (lb)[d]
Eggs	3.49[a]	0	0	0.00000000877[e]
Larvae	5.8[a]	0	0	0.00000236[e]
Age 1+	0.831[b]	0	0	0.00311[ff]
Age 2+	0.831[b]	0.1	0.5	0.0246[f]
Age 3+	0.286[b]	0.1	1	0.0749[f]
Age 4+	0.342[b]	0.1	1	0.145[f]
Age 5+	0.645[b]	0.1	1	0.229[f]
Age 6+	1.26[b]	0.1	1	0.624[g]

[a] Calculated from survival (Entergy Nuclear Generation Company, 2000) using the equation: (natural mortality) = -LN(survival) - (fishing mortality).
[b] Entergy Nuclear Generation Company, 2000.
[c] Commercial and recreational species, of minimal catch (Entergy Nuclear Generation Company, 2000). Fishing mortality and fraction vulnerable assumed.
[d] Weight calculated from length using the formula: $(6.0 \times 10^{-6}) \cdot Length(mm)^{3.22}$ = weight(g) (Serchuk and Cole, 1974).
[e] Length from Able and Fahay (1998).
[f] Length from Serchuk and Cole (1974).
[g] Length from Scott and Scott (1988).

Table G1-15: Fourbeard Rockling Species Parameters

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)[d]	Fraction Vulnerable to Fishery[d]	Weight (lb)[e]
Eggs	2.3[a]	0	0	0.00000000605[f]
Larvae	5.17[b]	0	0	0.000000896[f]
Age 1+	0.49[c]	0	0	0.00403[f]
Age 2+	0.49[c]	0	0	0.0347[f]
Age 3+	0.49[c]	0	0	0.0848[f]
Age 4+	0.49[c]	0	0	0.149[f]
Age 5+	0.49[c]	0	0	0.241[f]
Age 6+	0.49[c]	0	0	0.331[f]
Age 7+	0.49[c]	0	0	0.482[f]
Age 8+	0.49[c]	0	0	0.623[f]
Age 9+	0.49[c]	0	0	0.788[g]

[a] Calculated from assumed survival using the equation: (natural mortality) = -LN(survival) - (fishing mortality).
[b] Calculated from extrapolated survival using the equation: (natural mortality) = -LN(survival) - (fishing mortality).
[c] Froese and Pauly, 2001.
[d] Not a commercial or recreational species, thus no fishing mortality.
[e] Weight calculated from length using the formula: $(12.74 \times 10^{-6})*Length(mm)^{3.106}$ = weight(g) (Froese and Pauly, 2001).
[f] Length assumed based on Froese and Pauly (2001).
[g] Length from Froese and Pauly (2001).

Table G1-16: Grubby Species Parameters

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)[d]	Fraction Vulnerable to Fishery[d]	Weight (lb)[e]
Eggs	2.3[a]	0	0	0.000000211[f]
Larvae	4.7[b]	0	0	0.000359[f]
Age 1+	0.46[c]	0	0	0.00404[f]
Age 2+	0.46[c]	0	0	0.139[f]
Age 3+	0.46[c]	0	0	0.332[f]
Age 4+	0.46[c]	0	0	0.42[f]
Age 5+	0.46[c]	0	0	0.475[f]
Age 6+	0.46[c]	0	0	0.541[f]
Age 7+	0.46[c]	0	0	0.576[f]
Age 8+	0.46[c]	0	0	0.612[f]
Age 9+	0.46[c]	0	0	0.637[g]

[a] Calculated from assumed survival using the equation: (natural mortality) = -LN(survival) - (fishing mortality).
[b] Calculated from extrapolated survival using the equation: (natural mortality) = -LN(survival) - (fishing mortality).
[c] Froese and Pauly, 2001. Longhorn sculpin.
[d] Not a commercial or recreational species, thus no fishing mortality.
[e] Weight calculated from length using the formula for longhorn sculpin: $(1.034 \times 10^{-5})*Length(mm)^{3.003}$ = weight(g) (Clayton et al., 1978).
[f] Length assumed based on Clayton et al. (1978).
[g] Length for longhorn sculpin from Clayton et al. (1978).

Table G1-17: Hogchocker Species Parameters

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)[d]	Fraction Vulnerable to Fishery[d]	Weight (lb)[e]
Eggs	2.24[a]	0	0	0.000000237[f]
Larvae	6.73[b]	0	0	0.00123[f]
Age 1+	0.25[c]	0	0	0.00778[f]
Age 2+	0.25[c]	0	0	0.0295[f]
Age 3+	0.25[c]	0	0	0.0877[g]
Age 4+	0.25[c]	0	0	0.19[g]
Age 5+	0.25[c]	0	0	0.424[g]
Age 6+	0.25[c]	0	0	0.561[h]

[a] Calculated from survival (New England Power Company and Marine Research Inc., 1995) using the equation: (natural mortality) = -LN(survival) - (fishing mortality).
[b] Calculated from extrapolated survival using the equation: (natural mortality) = -LN(survival) - (fishing mortality).
[c] New England Power Company and Marine Research Inc., 1995.
[d] Not a commercial or recreational species, thus no fishing mortality.
[e] Weight calculated from length using the formula: $(1.947 \times 10^{-4}) \ast Length(mm)^{2.658} = weight(g)$ (Froese and Pauly, 2001).
[f] Length from Able and Fahay (1998).
[g] Length assumed based on Able and Fahay (1998) and Froese and Pauly (2001).
[h] Length from Froese and Pauly (2001).

Table G1-18: Little Skate Species Parameters

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)[d]	Fraction Vulnerable to Fishery[e]	Weight (lb)[f]
Eggs	2.94[a]	0	0	0.000774
Larvae	0.252[b]	0	0	0.0138
Age 1+	0.4[c]	0.4	0.5	0.157
Age 2+	0.4[c]	0.4	1	0.394
Age 3+	0.4[c]	0.4	1	0.75
Age 4+	0.4[c]	0.4	1	1.15
Age 5+	0.4[c]	0.4	1	1.51
Age 6+	0.4[c]	0.4	1	1.62
Age 7+	0.4[c]	0.4	1	1.65
Age 8+	0.4[c]	0.4	1	1.72

[a] Calculated from assumed survival using the equation: (natural mortality) = -LN(survival) - (fishing mortality).
[b] Calculated from extrapolated survival using the equation: (natural mortality) = -LN(survival) - (fishing mortality).
[c] NOAA, 1993.
[d] NOAA, 2001c.
[e] Commercial species assumed to be vulnerable to fishing mortality at age 1.
[f] Weight calculated from length (Scott and Scott, 1988) using the formula: $(8.32 \times 10^{-6}) \ast Length(mm)^{2.972} = weight(g)$ (Froese and Pauly, 2001).

Table G1-19: Lumpfish Species Parameters

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)[d]	Fraction Vulnerable to Fishery[d]	Weight (lb)[e]
Eggs	2.3[a]	0	0	0.0000004[f]
Larvae	9.39[b]	0	0	0.000993[f]
Age 1+	0.19[c]	0	0	0.0147[g]
Age 2+	0.19[c]	0	0	0.0584[h]
Age 3+	0.19[c]	0	0	0.149[g]
Age 4+	0.19[c]	0	0	0.686[h]
Age 5+	0.19[c]	0	0	1.86[g]

[a] Calculated from survival for Atlantic silverside (Stone & Webster Engineering Corporation, 1977) using the equation: (natural mortality) = -LN(survival) - (fishing mortality).
[b] Calculated from extrapolated survival using the equation: (natural mortality) = -LN(survival) - (fishing mortality).
[c] Froese and Pauly, 2001.
[d] Not a commercial or recreational species, thus no fishing mortality.
[e] Weight calculated from length using the formula: $(6.755 \times 10^{-5}) \times Length(mm)^{2.939} = weight(g)$ (Froese and Pauly, 2001).
[f] Length for rock gunnel from Able and Fahay (1998).
[g] Length assumed based on Able and Fahay (1998).

Table G1-20: Northern Pipefish Species Parameters

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)[d]	Fraction Vulnerable to Fishery[d]	Weight (lb)[e]
Eggs	2.3[a]	0	0	0.0000000157[f]
Larvae	3.31[b]	0	0	0.00168[f]
Age 1+	0.75[c]	0	0	0.00871[g]
Age 2+	0.75[c]	0	0	0.0124[g]
Age 3+	0.75[c]	0	0	0.0168[g]
Age 4+	0.75[c]	0	0	0.0222[g]
Age 5+	0.75[c]	0	0	0.0285[f]

[a] Calculated from assumed survival (Stone & Webster Engineering Corporation, 1977) (Atlantic silverside) using the equation: (natural mortality) = -LN(survival) - (fishing mortality).
[b] Calculated from extrapolated survival using the equation: (natural mortality) = -LN(survival) - (fishing mortality).
[c] Froese and Pauly, 2001. Broad-nosed pipefish.
[d] Not a commercial or recreational species, thus no fishing mortality.
[e] Weight calculated from length using the formula for sargassum pipefish: $(9.407 \times 10^{-6}) \times Length(mm)^{2.66} = weight(g)$ (Froese and Pauly, 2001).
[f] Length from Scott and Scott (1988).
[g] Length assumed based on Scott and Scott (1988).

Table G1-21: Pollock Species Parameters

Stage Name	Natural Mortality (per stage)[a]	Fishing Mortality (per stage)[b]	Fraction Vulnerable to Fishery[c]	Weight (lb)[d]
Eggs	0.922	0	0	0.0000000203[e]
Larvae	4.07	0	0	0.00000104[f]
Juvenile	6.93	0	0	0.00166[e]
Age 1+	0.2	0	0	0.657[f]
Age 2+	0.2	0.2	0.5	1.3[f]
Age 3+	0.2	0.2	1	1.73[f]
Age 4+	0.2	0.2	1	3.24[f]
Age 5+	0.2	0.2	1	4.93[f]
Age 6+	0.2	0.2	1	5.7[f]
Age 7+	0.2	0.2	1	6.83[f]
Age 8+	0.2	0.2	1	8.46[f]
Age 9+	0.2	0.2	1	9.93[f]
Age 10+	0.2	0.2	1	12[f]
Age 11+	0.2	0.2	1	14.8[f]
Age 12+	0.2	0.2	1	16.4[f]
Age 13+	0.2	0.2	1	18.1[f]
Age 14+	0.2	0.2	1	19.9[f]
Age 15+	0.2	0.2	1	21.2[f]

[a] Saila et al., 1997.
[b] NOAA, 2001c.
[c] Commercial and recreational species. Assumed to be vulnerable to fishing mortality at age 2.
[d] Weight calculated from length using the formula: $(6.894 \times 10^{-6})*Length(mm)^{3.048} = weight(g)$ (Froese and Pauly, 2001).
[e] Length from Able and Fahay (1998).
[f] Length from Saila et al. (1997).

Table G1-22: Radiated Shanny Species Parameters

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)[d]	Fraction Vulnerable to Fishery[d]	Weight (lb)[e]
Eggs	2.3[a]	0	0	0.0000000091[f]
Larvae	3.11[b]	0	0	0.00000948[f]
Age 1+	0.44[c]	0	0	0.000622[f]
Age 2+	0.44[c]	0	0	0.00415[f]
Age 3+	0.44[c]	0	0	0.00846[f]
Age 4+	0.44[c]	0	0	0.0151[f]
Age 5+	0.44[c]	0	0	0.0194[f]
Age 6+	0.44[c]	0	0	0.0244[f]
Age 7+	0.44[c]	0	0	0.0303[f]
Age 8+	0.44[c]	0.	0	0.0336[g]

[a] Calculated from assumed survival using the equation: (natural mortality) = -LN(survival) - (fishing mortality).
[b] Calculated from extrapolated survival using the equation: (natural mortality) = -LN(survival) - (fishing mortality).
[c] Froese and Pauly, 2001.
[d] Not a commercial or recreational species, thus no fishing mortality.
[e] Weight calculated from length using the formula for rock gunnel: $(4.125 \times 10^{-6}) \ast \text{Length(mm)}^{3.018} = \text{weight(g)}$ (Froese and Pauly, 2001).
[f] Length assumed based on Froese and Pauly (2001).
[g] Length from Froese and Pauly (2001).

Table G1-23: Rainbow Smelt Species Parameters

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)[c]	Fraction Vulnerable to Fishery[c]	Weight (lb)[d]
Eggs	3.32[a]	0	0	0.0000000861[e]
Larvae	2.66[a]	0	0	0.00273[e]
Age 1+	0.72[b]	0	0	0.0359[f]
Age 2+	0.72[b]	0	0	0.134[f]
Age 3+	0.72[b]	0	0	0.289[f]
Age 4+	0.72[b]	0	0	0.585[f]
Age 5+	0.72[b]	0	0	0.942[f]
Age 6+	0.72[b]	0	0	1.27[g]

[a] Calculated from survival (Stone & Webster Engineering Corporation, 1977) using the equation: (natural mortality) = -LN(survival) - (fishing mortality).
[b] Froese and Pauly, 2001.
[c] Not a commercial or recreational species, thus no fishing mortality.
[d] Weight calculated from length using the formula: $(3.903 \times 10^{-5}) \ast \text{Length(mm)}^{2.81} = \text{weight(g)}$ (Froese and Pauly, 2001).
[e] Length from Able and Fahay (1998).
[f] Length assumed based on Able and Fahay (1998) and Froese and Pauly (2001).
[g] Length from Froese and Pauly (2001).

Table G1-24: Red Hake Species Parameters

Stage Name	Natural Mortality (per stage)[a]	Fishing Mortality (per stage)[b]	Fraction Vulnerable to Fishery[c]	Weight (lb)[d]
Eggs	1.22	0	0	0.00000000238[e]
Larvae 2mm	0.67	0	0	0.0000000535[f]
Larvae 2.5mm	0.67	0	0	0.000000109[f]
Larvae 3.0mm	0.67	0	0	0.000000194[f]
Larvae 3.5mm	0.67	0	0	0.000000316[f]
Larvae 4.0mm	0.67	0	0	0.000000482[f]
Larvae4.5mm	3.35	0	0	0.000000701[f]
Juvenile	4.83	0	0	0.00145[f]
Age 1+	0.4	0.39	0.5	0.124[f]
Age 2+	0.4	0.39	1	0.465[g]
Age 3+	0.4	0.39	1	0.578[g]
Age 4+	0.4	0.39	1	0.723[g]
Age 5+	0.4	0.39	1	0.928[g]
Age 6+	0.4	0.39	1	1.17[h]
Age 7+	0.4	0.39	1	1.45[h]
Age 8+	0.4	0.39	1	1.78[h]
Age 9+	0.4	0.39	1	2.15[h]
Age 10+	0.4	0.39	1	2.3[g]

[a] Saila et al., 1997.
[b] NOAA, 2001c.
[c] Commercial species. Assumed to be vulnerable to fishing mortality at age 1.
[d] Weight calculated from length using the formula for white hake: $(2.692 \times 10^{-6}) \ast Length(mm)^{3.172} = weight(g)$ (Froese and Pauly, 2001).
[e] Length from Able and Fahay (1998).
[f] Length from Saila et al. (1997).
[g] Length from Scott and Scott (1988).
[h] Length assumed based on Scott and Scott (1988).

Table G1-25: Rock Gunnel Species Parameters

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)[d]	Fraction Vulnerable to Fishery[d]	Weight (lb)[e]
Eggs	2.3[a]	0	0	0.0000000737[f]
Larvae	2.57[b]	0	0	0.00000948[g]
Age 1+	0.44[c]	0	0	0.00382[f]
Age 2+	0.44[c]	0	0	0.0128[f]
Age 3+	0.44[c]	0	0	0.0223[f]
Age 4+	0.44[c]	0	0	0.0371[f]
Age 5+	0.44[c]	0	0	0.049[f]

[a] Calculated from assumed survival using the equation: (natural mortality) = -LN(survival) - (fishing mortality).
[b] Calculated from extrapolated survival using the equation: (natural mortality) = -LN(survival) - (fishing mortality).
[c] Froese and Pauly, 2001. Radiated shanny.
[d] Not a commercial or recreational species, thus no fishery mortality.
[e] Weight calculated from length using the formula: $(4.125 \times 10^{-6}) \ast Length(mm)^{3.018} = weight(g)$ (Froese and Pauly, 2001).
[f] Length from Scott and Scott (1988).
[g] Length assumed based on Scott and Scott (1988).

Table G1-26: Sculpin Species Parameters

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)[d]	Fraction Vulnerable to Fishery[d]	Weight (lb)[e]
Eggs	2.3[a]	0	0	0.000000211[f]
Larvae	4.7[b]	0	0	0.000359[f]
Age 1+	0.46[c]	0	0	0.00404[g]
Age 2+	0.46[c]	0	0	0.139[g]
Age 3+	0.46[c]	0	0	0.332[g]
Age 4+	0.46[c]	0	0	0.42[g]
Age 5+	0.46[c]	0	0	0.475[g]
Age 6+	0.46[c]	0	0	0.541[g]
Age 7+	0.46[c]	0	0	0.576[g]
Age 8+	0.46[c]	0	0	0.612[g]
Age 9+	0.46[c]	0	0	0.637[g]

[a] Calculated from assumed survival (Stone & Webster Engineering Corporation, 1977) (Atlantic silverside) using the equation: (natural mortality) = -LN(survival) - (fishing mortality).

[b] Calculated from extrapolated survival using the equation: (natural mortality) = -LN(survival) - (fishing mortality).

[c] Froese and Pauly, 2001. Longhorn sculpin.

[d] Not a commercial or recreational species, thus no fishing mortality.

[e] Weight calculated from length using the formula for longhorn sculpin: $(1.034 \times 10^{-5}) * Length(mm)^{3.003} =$ weight(g) (Clayton et al., 1978).

[f] Length assumed based on Clayton et al. (1978).

[g] Length from Clayton et al. (1978). Longhorn sculpin.

Table G1-27: Scup Species Parameters

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)[d]	Fraction Vulnerable to Fishery[e]	Weight (lb)[f]
Eggs	2.3[a]	0	0	0.000000354[g]
Larvae	5.47[b]	0	0	0.00107[g]
Age 1+	0.29[c]	0.14	0.5	0.073[g]
Age 2+	0.29[c]	0.14	1	0.244[g]
Age 3+	0.29[c]	0.14	1	0.495[h]
Age 4+	0.29[c]	0.14	1	0.806[h]
Age 5+	0.29[c]	0.14	1	1.1[h]
Age 6+	0.29[c]	0.14	1	1.46[h]
Age 7+	0.29[c]	0.14	1	1.88[h]
Age 8+	0.29[c]	0.14	1	2.37[h]
Age 9+	0.29[c]	0.14	1	2.94[h]
Age 10+	0.29[c]	0.14	1	3.58[h]
Age 11+	0.29[c]	0.14	1	4.3[h]
Age 12+	0.29[c]	0.14	1	4.83[h]
Age 13+	0.29[c]	0.14	1	4.97[g]

[a] Calculated from assumed survival (Stone & Webster Engineering Corporation, 1977) (Atlantic silverside) using the equation: (natural mortality) = -LN(survival) - (fishing mortality).

[b] Calculated from extrapolated survival using the equation: (natural mortality) = -LN(survival) - (fishing mortality).

[c] Froese and Pauly, 2001.

[d] NOAA, 2001c.

[e] Commercial and recreational species. Assumed to be vulnerable to fishing mortality at age 1.

[f] Weight calculated from length using the formula for sheepshead porgy: $(1.649 \times 10^{-4})*Length(mm)^{2.666} = weight(g)$ (Froese and Pauly, 2001).

[g] Length from Clayton et al. (1978).

[h] Length assumed based on Clayton et al. (1978).

Table G1-28: Searobin Species Parameters

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)[d]	Fraction Vulnerable to Fishery[e]	Weight (lb)[f]
Eggs	2.3[a]	0	0	0.00000286[g]
Larvae	4.57[b]	0	0	0.0000229[g]
Age 1+	0.42[c]	0.1	0.5	0.0231[g]
Age 2+	0.42[c]	0.1	1	0.185[g]
Age 3+	0.42[c]	0.1	1	0.361[g]
Age 4+	0.42[c]	0.1	1	0.564[g]
Age 5+	0.42[c]	0.1	1	0.758[g]
Age 6+	0.42[c]	0.1	1	0.992[g]
Age 7+	0.42[c]	0.1	1	1.17[g]
Age 8+	0.42[c]	0.1	1	1.27[h]

[a] Calculated from assumed survival using the equation: (natural mortality) = -LN(survival) - (fishing mortality).

[b] Calculated from extrapolated survival using the equation: (natural mortality) = -LN(survival) - (fishing mortality).

[c] Froese and Pauly, 2001. Northern searobin.

[d] Assumed based on hake (Saila et al., 1997).

[e] Recreational species. Assumed to be vulnerable to fishing mortality at age 1.

[f] Weight calculated from length using the formula for longhorn sculpin: $(1.034 \times 10^{-5}) * Length(mm)^{3.003} =$ weight(g) (Clayton et al., 1978).

[g] Length assumed based on Froese and Pauly (2001).

[h] Length from Froese and Pauly (2001).

Table G1-29: Striped Bass Species Parameters

Stage Name	Natural Mortality (per stage)[a]	Fishing Mortality (per stage)[b]	Fraction Vulnerable to Fishery[a]	Weight (lb)
Eggs	1.39	0	0	0.000022[c]
Yolksac larvae	2.22	0	0	0.097[c]
Post-yolksac larvae	5.08	0	0	0.194[c]
Juvenile 1	2.28	0	0	0.291[c]
Juvenile 2	1	0	0	0.388[c]
Age 1+	1.1	0	0	0.485[d]
Age 2+	0.15	0.31	0.06	2.06[d]
Age 3+	0.15	0.31	0.2	3.31[d]
Age 4+	0.15	0.31	0.63	4.93[d]
Age 5+	0.15	0.31	0.94	6.5[d]
Age 6+	0.15	0.31	1	8.58[d]
Age 7+	0.15	0.31	0.9	12.3[d]
Age 8+	0.15	0.31	0.9	14.3[d]
Age 9+	0.15	0.31	0.9	16.1[d]
Age 10+	0.15	0.31	0.9	18.8[d]
Age 11+	0.15	0.31	0.9	19.6[d]
Age 12+	0.15	0.31	0.9	22.4[d]
Age 13+	0.15	0.31	0.9	27[d]
Age 14+	0.15	0.31	0.9	34.6[d]
Age 15+	0.15	0.31	0.9	41.5[d]

[a] PSEG, 1999c.
[b] NOAA, 2001c.
[c] Length assumed based on PSEG (1999c).
[d] Length from PSEG (1999c).

Table G1-30: Striped Killifish Species Parameters

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)[c]	Fraction Vulnerable to Fishery[c]	Weight (lb)[d]
Eggs	2.3[a]	0	0	0.000000864[e]
Larvae	3[b]	0	0	0.0000182[e]
Age 1+	0.777[b]	0	0	.0121[f]
Age 2+	0.777[b]	0	0	0.0327[f]
Age 3+	0.777[b]	0	0	0.0551[f]
Age 4+	0.777[b]	0	0	0.0778[f]
Age 5+	0.777[b]	0	0	0.0967[f]
Age 6+	0.777[b]	0	0	0.113[f]
Age 7+	0.777[b]	0	0	0.158[f]

[a] Calculated from survival for Atlantic silverside (Stone & Webster Engineering Corporation, 1977) using the equation: (natural mortality) = -LN(survival) - (fishing mortality).
[b] Calculated from survival for mummichog (Meredith and Lotrich, 1979) using the equation: (natural mortality) = -LN(survival) - (fishing mortality).
[c] Not a commercial or recreational species, thus no fishing mortality.
[d] Weight calculated from length using the formula: $(2.6 \times 10^{-5}) \ast \text{Length(mm)}^{2.96} = \text{weight(g)}$ (Carlander, 1969).
[e] Length from Able and Fahay (1998).
[f] Length from Carlander (1969).

Table G1-31: Tautog Species Parameters

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)[c]	Fraction Vulnerable to Fishery[d]	Weight (lb)[e]
Eggs	2.53[a]	0	0	0.0000000689[f]
Larvae	9.75[a]	0	0	0.00000185[f]
Age 1+	0.06[b]	0.29	0.5	0.0104[g]
Age 2+	0.06[b]	0.29	1	0.183[h]
Age 3+	0.06[b]	0.29	1	1.4[h]
Age 4+	0.06[b]	0.29	1	3.27[h]
Age 5+	0.06[b]	0.29	1	4.62[h]
Age 6+	0.06[b]	0.29	1	6.3[g]

[a] Calculated from survival (New England Power Company and Marine Research Inc., 1995) using the equation: (natural mortality) = -LN(survival) - (fishing mortality).
[b] New England Power Company and Marine Research Inc., 1995.
[c] Atlantic States Marine Fisheries Commission, 2000e.
[d] Commercial and recreational species. Assumed to be vulnerable to fishing mortality at age 1.
[e] Weight calculated from length using the formula: $(3.318 \times 10^{-5}) \ast Length(mm)^{2.94} = weight(g)$ (Froese and Pauly, 2001).
[f] Length from Able and Fahay (1998).
[g] Length from Scott and Scott (1988).
[h] Length assumed based on Scott and Scott (1988).

Table G1-32: Threespine Stickleback Species Parameters

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)[d]	Fraction Vulnerable to Fishery[d]	Weight (lb)[e]
Eggs	2.3[a]	0	0	0.0000000227[f]
Larvae	3.53[b]	0	0	0.00000127[f]
Age 1+	0.9[c]	0	0	0.000064[g]
Age 2+	0.9[c]	0	0	0.000244[g]
Age 3+	0.9[c]	0	0	0.000422[g]
Age 4+	0.9[c]	0	0	0.00203[g]

[a] Calculated from survival (Stone & Webster Engineering Corporation, 1977) (Atlantic silverside) using the equation: (natural mortality) = -LN(survival) - (fishing mortality).
[b] Calculated from extrapolated survival using the equation: (natural mortality) = -LN(survival) - (fishing mortality).
[c] Froese and Pauly, 2001.
[d] Not a commercial or recreational species, thus no fishing mortality.
[e] Weight calculated from length using the formula for sea stickleback: $(2.10 \times 10^{-6}) \ast Length(mm)^{3.00} = weight(g)$ (Froese and Pauly, 2001).
[f] Length from Wang (1986a).
[g] Length from Scott and Scott (1988).

Table G1-33: White Perch Species Parameters

Stage Name	Natural Mortality (per stage)[a]	Fishing Mortality (per stage)[a]	Fraction Vulnerable to Fishery[a]	Weight (lb)
Eggs	2.75	0	0	0.000022[b]
Yolksac larvae	2.1	0	0	0.00946[b]
Post-yolksac larvae	3.27	0	0	0.0189[b]
Juvenile 1	0.947	0	0	0.0283[b]
Juvenile 2	0.759	0	0	0.0378[b]
Age 1+	0.693	0	0	0.0472[a]
Age 2+	0.693	0	0	0.0567[a]
Age 3+	0.693	0.15	0.0008	0.103[a]
Age 4+	0.689	0.15	0.0266	0.15[a]
Age 5+	1.58	0.15	0.212	0.214[a]
Age 6+	1.54	0.15	0.48	0.265[a]
Age 7+	1.48	0.15	0.838	0.356[a]
Age 8+	1.46	0.15	1	0.387[a]
Age 9+	1.46	0.15	1	0.516[a]
Age 10+	1.46	0.15	1	0.619[a]

[a] PSEG, 1999c.
[b] Assumed based on PSEG, 1999c.

Table G1-34: Windowpane Species Parameters

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)[d]	Fraction Vulnerable to Fishery[e]	Weight (lb)[f]
Eggs	2.64[a]	0	0	0.0000000818
Larvae	6.47[b]	0	0	0.00000847
Age 1+	0.39[c]	1.6	0.02	0.00634
Age 2+	0.39[c]	1.6	0.25	0.0409
Age 3+	0.39[c]	1.6	0.61	0.188
Age 4+	0.39[c]	1.6	1	0.384
Age 5+	0.39[c]	1.6	1	0.548
Age 6+	0.39[c]	1.6	1	0.663
Age 7+	0.39[c]	1.6	1	0.808
Age 8+	0.39[c]	1.6	1	2.53

[a] Calculated from survival (New England Power Company and Marine Research Inc., 1995) using the equation: (natural mortality) = -LN(survival) - (fishing mortality).
[b] Calculated from extrapolated survival using the equation: (natural mortality) = -LN(survival) - (fishing mortality).
[c] Froese and Pauly, 2001.
[d] NOAA, 2001c.
[e] USGen New England, 2001. Winter flounder.
[f] Weight calculated from length (Clayton et al., 1978) using the formula: $(2.10 \times 10^{-6}) \ast \text{Length(mm)}^{3.00} = \text{weight(g)}$ (Clayton et al., 1978).

Table G1-35: Winter Flounder Species Parameters

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)[d]	Fraction Vulnerable to Fishery[c]	Weight (lb)[e]
Eggs	5.39[a]	0	0	0.00000000726[f]
Larvae 1	0.354[bb]	0	0	0.000000442[g]
Larvae 2	0.708[b]	0	0	0.00000108[g]
Larvae 3	2.83[b]	0	0	0.00000933[g]
Larvae 4	0.708[b]	0	0	0.0000135[g]
Juvenile	1.77[b]	0	0	0.000161[h]
Age 1+	0.2[c]	0.24	0.01	0.012[i]
Age 2+	0.2[c]	0.24	0.29	0.182[i]
Age 3+	0.2[c]	0.24	0.8	0.425[i]
Age 4+	0.2[c]	0.24	0.92	0.738[i]
Age 5+	0.2[c]	0.24	0.83	1.08[i]
Age 6+	0.2[c]	0.24	0.89	1.4[i]
Age 7+	0.2[c]	0.24	0.89	1.69[i]
Age 8+	0.2[c]	0.24	0.89	1.94[i]
Age 9+	0.2[c]	0.24	0.89	2.16[i]
Age 10+	0.2[c]	0.24	0.89	2.33[i]
Age 11+	0.2[c]	0.24	0.89	2.49[i]
Age 12+	0.2[c]	0.24	0.89	2.61[i]

[a] Calculated from survival (PG&E Generating and Marine Research Inc., 1999) using the equation: (natural mortality) = -LN(survival) - (fishing mortality).

[b] Calculated from survival (Saila et al., 1997) using the equation: (natural mortality) = -LN(survival) - (fishing mortality).

[c] Colarusso, 2000.

[d] NOAA, 2001c.

[e] Weight calculated from length using the formula: $(6.591 \times 10^{-6}) \ast Length(mm)^{3.109} = weight(g)$ (Colarusso, 2000).

[f] Length from Able and Fahay (1998).

[g] Length from Saila et al. (1997).

[h] Length assumed based on Saila et al. (1997) and Colarusso (2000).

[i] Length from Colarusso (2000).