United States
Environmental Protection
Agency

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

Part F - G

May 2002

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

CHAPTER CONTENTS



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.

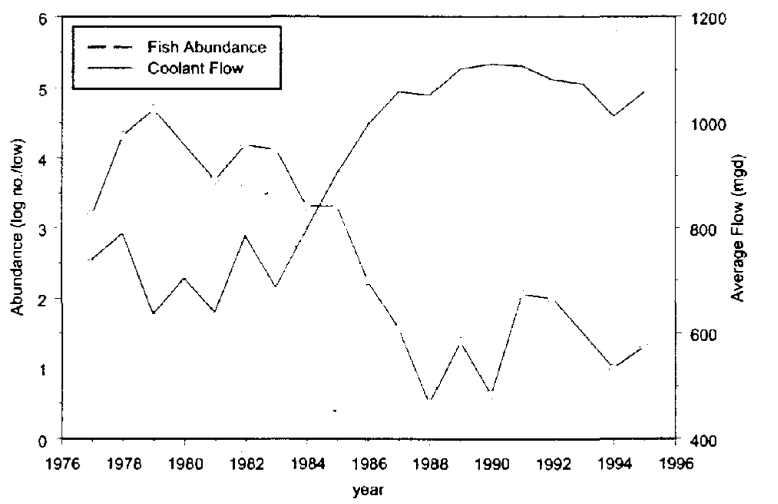
With a capacity of 1,611 megawatts, Brayton Point Station is the largest fossil fuel burning steam-electric generating facility in New England. The station uses a once-through-cooling water system and is allowed by its current NPDES permit to withdraw up to 1.452 billion gallons a day ( BGD) of cooling 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




*Sources*: Gibson, 1996; personal communication, Meredith Simas, Environmental Engineer, Brayton Point Station, March 23, 2001.

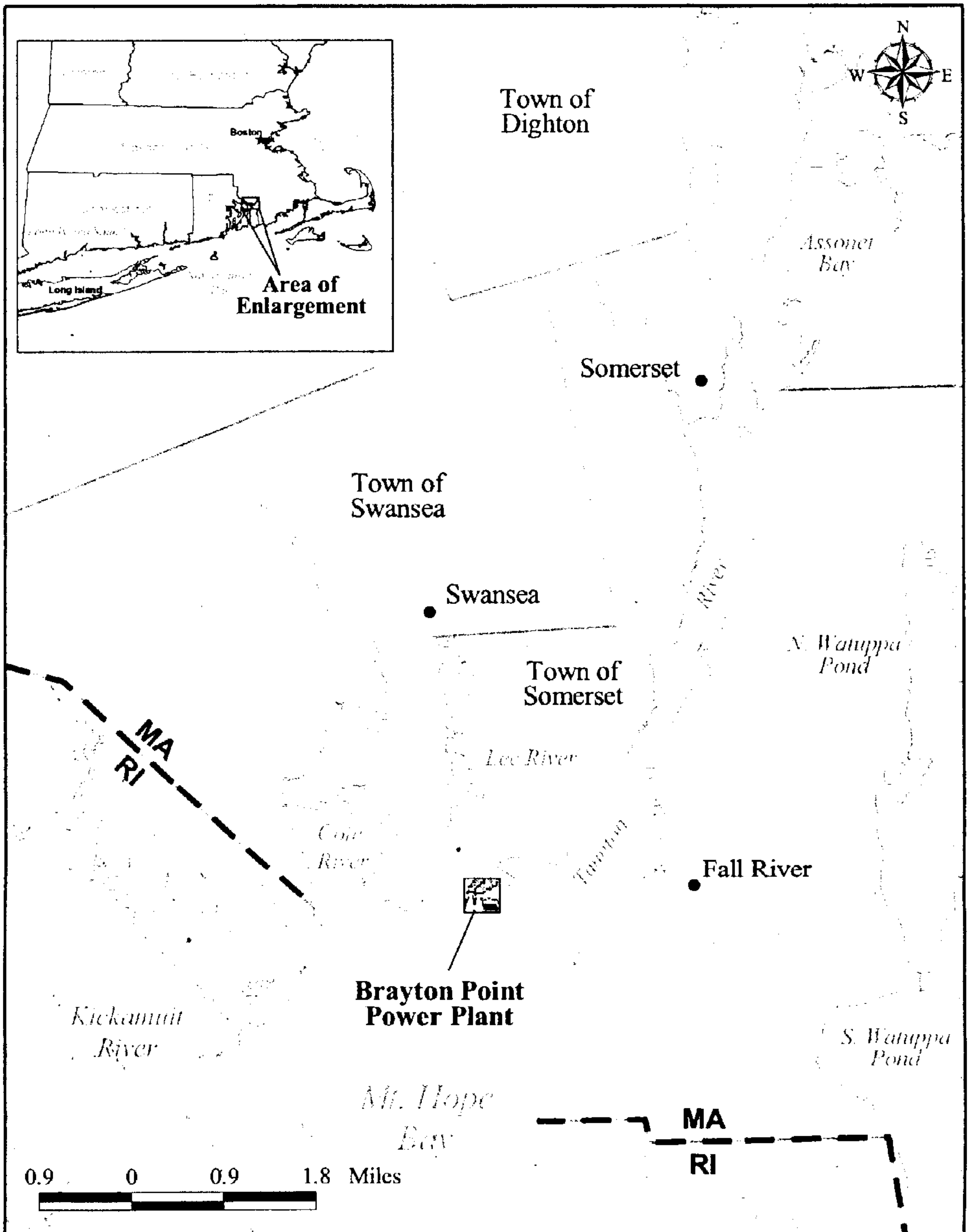
A more recent analysis by the RIDEM (Gibson, 2001) attempted to control for other regional stressors that may be contributing to winter flounder declines, including overfishing, increased winter water temperatures, and increased predation on larvae by the shrimp *Crangon septemspinosa* (Keller and Klein-MacPhee, 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




j:/projects/intake/aprs_amls/case_plants_mod.apr

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.)

[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 Boston Globe.

❖ *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 $km^2$ (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.

CHAPTER CONTENTS



## 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.

[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:<br>▸ Source water: Taunton River<br>▸ Six intake bays (2 for each unit)<br>▸ Conventional once-through system<br>▸ Trash rack<br>▸ Conventional traveling screen (rotated every 8 hours)<br>▸ High pressure spray wash (120 psi) to remove debris and fish<br>▸ Sluiceway to carry debris and fish to discharge point beyond the influence of the intake structure<br>▸ Design intake flow: 925 MGD<br><br>*Seasonal Variation:*<br>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:<br>▸ Source Water: Lee River<br>▸ One intake bay<br>▸ Closed-cycle cooling system<br>▸ Trash racks<br>▸ 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:<br>▸ Source water: Lee River<br>▸ One intake bay<br>▸ Trash racks<br>▸ Angled traveling screens. Six traveling screens set 25° from upstream flow.<br>▸ Fish bypass intakes at the apex of angled screens.<br>▸ Fish baskets (with water retention) mounted to screens.<br>▸ Low-pressure spray to remove impinged fish.<br>▸ High-pressure spray to remove debris.<br>▸ Separate fish and debris troughs.<br>▸ Screens rotate at various speeds depending on water differential.<br>▸ 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

---

[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.

[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.

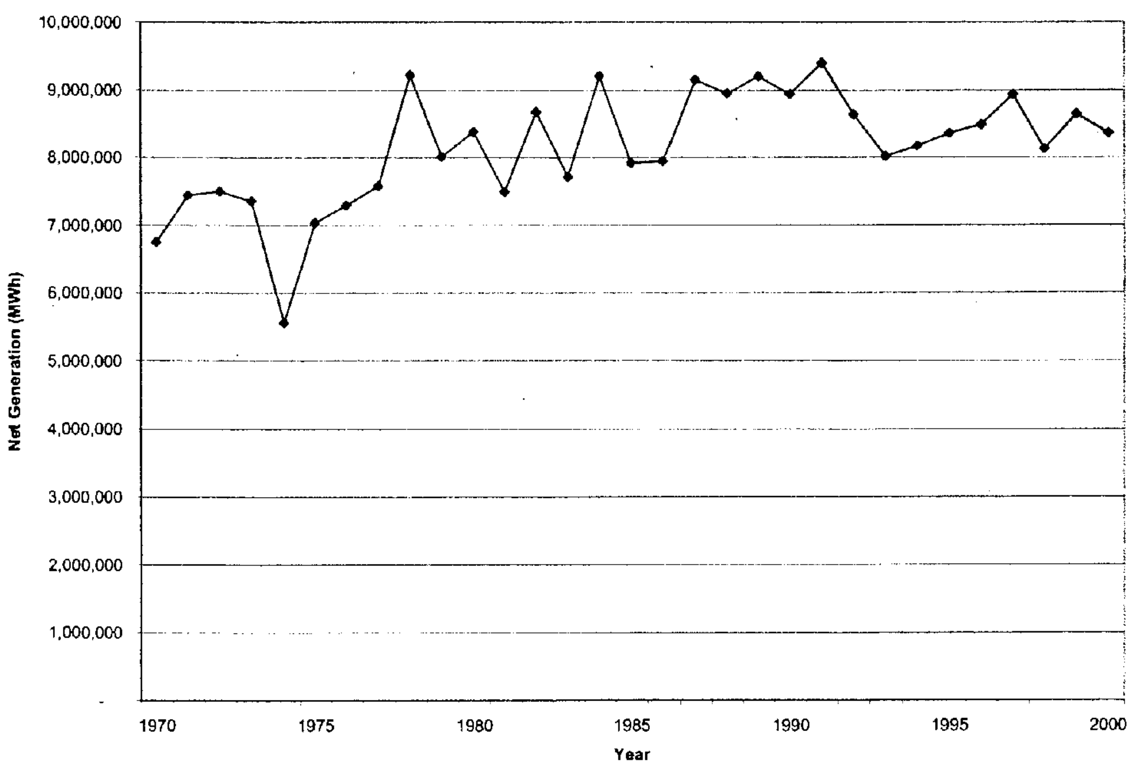
Table F2-4 presents details for Brayton Point's eight units.

| Table F2-4: 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, 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.

CHAPTER CONTENTS



## 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 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 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).

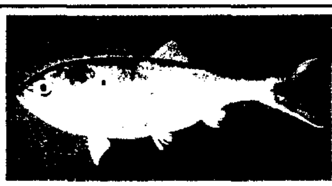
Atlantic menhaden spawn year round at sea and in larger bays (Scott and Scott, 1988). Spawning peaks during the southward fall migration and continues throughout the winter off the North Carolina coast. There is limited spawning during the northward migration and during summer months (Hall, 1995). The 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*)**

**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]

**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:**

***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.[c]

**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.
[c] 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.esv

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 for 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 | Hogchoker | Rainbow Smelt | Scup | Seaboard Goby | Silver Hake | Tautog | Threespine Stickleback | Weakfish | White Perch | Windowpane | 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/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 | Alewife | American Sand Lance | Atlantic Menhaden | Atlantic Silverside | Bay Anchovy | Hogchoker | Rainbow Smelt | Scup | Seaboard Goby | Silver Hake | Tautog | Threespine Stickleback | Weakfish | White Perch | Windowpane | 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
mixed.rollup.chap3.ent Wed Feb 13 13:28:54 MST 2002
P:/Intake/Brayton/Brayton_Science/scodes/tables.output.projected01/flowchart.chap3.ENT.csv

# 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.

CHAPTER CONTENTS



## 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<br>Bottom fish<br>Flatfish | $9.54<br>$2.54<br>$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<br>Bottom fish<br>Flatfish | $3.61<br>$2.40<br>$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)<br>Small game fish (striped bass)<br>Flatfish (flounder) | $11.50<br>$18.14<br>$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.

CHAPTER CONTENTS



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

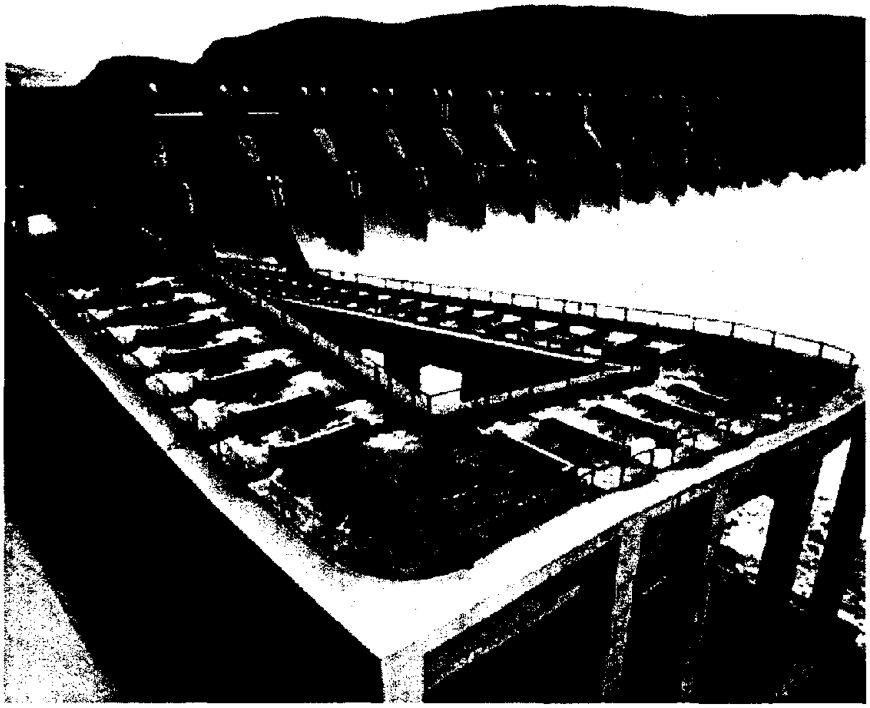
Tautog, which are impinged and entrained at Brayton Point, use rocky or reef-like habitats with interstices that provide refuge from predators, especially during the night when the fish become torpid. These habitats can be created artificially with cobbles, concrete, and other suitable materials.

## 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 $m^2$)[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 $m^2$ and shoot biomass (wet) > 100 g/$m^2$.
*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 m$^2$) | |
|---|---|---|---|
| | | 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 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 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 m$^2$) | | |
|---|---|---|---|---|
| | | 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 $m^2$ of Tidal Wetland | Sampling Efficiency Adjustment Factor | Life Stage Adjustment Factor | Restored Habitat Service Flow Adjustment Factor | Sampling Time and Location Adjustment Factor | Increased Production of Age 1 Fish per $m^2$ of Restored Tidal Wetland[b,c] |
|---|---|---|---|---|---|---|---|---|
| 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 $m^2$ of Tidal Wetland | Sampling Efficiency Adjustment Factor | Life Stage Adjustment Factor | Restored Habitat Service Flow Adjustment Factor | Sampling Time and Location Adjustment Factor | Increased Production of Age 1 Fish per $m^2$ of Restored Tidal Wetland[b] |
|---|---|---|---|---|---|---|---|---|
| Striped killifish | Raposa, in press | Galilee Marsh — 1999 | 12.40 | 1.6 | 0.6054 | 1 | 11.90 | 1.01 |
| | **Species average** | | | | | | | **0.19** |

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

## 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 m$^2$ of Revegetated Substrate (rounded) | Number of 100 m$^2$ 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 $m^2$ of Restored Tidal Wetland (rounded) | Number of $m^2$ Units of Restored Tidal Wetland Required to Offset Estimated Average Annual I&E loss[a] |
|---|---|---|---|
| Winter flounder | 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 $m^2$ of Artificial Reef (rounded) | Number of $m^2$ Units of Artificial Reef Surface Habitat Required to Offset Estimated Average Annual I&E Loss |
|---|---|---|---|
| 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 $m^2$, in each acre of seabed to be revegetated at a SAV restoration site (personal communication, P. Colarusso, U.S. EPA Region 1, 2002). Assuming complete coverage over time, this results in a ratio of plantings to total coverage of between 1:31 (130 1 $m^2$ TERFS / 4,047 $m^2$ per acre) and 1:34 (120 1 $m^2$ TERFS / 4,047 $m^2$ per acre).

However, the initially bare areas between transplants do not revegetate immediately and the unit costs need to be adjusted accordingly. Therefore, EPA assumed that the area covered with SAV would double each year. Under this assumption, the entire restoration area would be completely covered with SAV in the sixth year of the restoration project. Using the habitat equivalency analysis (HEA) method (Peacock, 1999), the present value of the natural resource service flows from the SAV over the 6 year revegetation scenario is 90 percent of that provided by a scenario where the entire restoration area is instantaneously revegetated with transplanted shoots.[1] Therefore, EPA applied 90 percent of the 1:34 planting-to-coverage ratio, or 1:30 as an adjustment factor to Save the Bay's cost estimates to account for the expected spreading from transplanted sites to bare areas in a SAV restoration area. Table 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 $m^2$ of SAV Restored | Cost per 100 $m^2$ of SAV Restored |
|---|---|---|
| Direct restoration (shoot collection and transplant) | $1,940 | $194,000 |
| Contingency costs (10% of direct restoration) | $194 | $19,400 |
| Restoration site assessment (1% of direct restoration) | $19 | $1,900 |
| Subtotal without allowance for distribution of transplanted SAV shoots | $2,154 | $215,400 |
| Discounted planting to coverage ratio for transplanted SAV | 30:1 | 30:1 |
| Final implementation unit costs | $71.80 | $7,180 |
| Annualized implementation unit costs | $6.76 | $676 |

### 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.

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

### 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 $m^2$ 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).

---

[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: Species | Species Benefitting from the Restoration Alternative: Average Annual I&E Loss of Age 1 Equivalents | Required Units of Restoration Implementation[a] | Units of Measure for Preferred Restoration Alternative | Total Annualized Unit Cost | Total Annualized Cost |
|---|---|---|---|---|---|---|
| Restore SAV | Scup<br>Threespine stickleback<br>Weakfish | 509<br>3,385<br>1,092 | **6,638**<br>301<br>Unknown | 100 m$^2$ of directly revegetated substrate | $1,233.50 | $8,187.978 |
| Restore tidal wetland | Winter flounder<br>Atlantic silverside<br>Striped killifish | 520,715<br>17,112<br>572 | **10,274,236**<br>343,247<br>3,031 | m$^2$ of restored tidal wetland | $1.95 | $20,069,076 |
| Create artificial reefs | Tautog | 31,379 | **40,915,621** | m$^2$ of reef surface area | $24.85 | $1,016,911,890 |
| Install fish passageways | Alewife<br>Rainbow smelt<br>White perch | 9,315<br>50,784<br>2,297 | **1.00**<br>Unknown<br>Unknown | New fish passageway | $49,438 | $49,438[b] |
| Species not valued | Seaboard goby<br>Bay anchovy<br>American sand lance<br>Hogchoker<br>Atlantic menhaden<br>Windowpane<br>Silver hake<br>Butterfish | 1,513,836<br>1,237,140<br>453,236<br>47,116<br>13,146<br>8,689<br>5,775<br>278 | 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 | | | | | | $1,045,218,361 |
| 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<br>Scup<br>Weakfish | 2,732<br>0<br>600 | **243**<br>0<br>Unknown | 100 m² of directly revegetated substrate | $1,233.50 | $299,741 |
| Restore tidal wetland | Winter flounder<br>Atlantic silverside<br>Striped killifish | 13,601<br>9,113<br>572 | **268,362**<br>182,796<br>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<br>White perch<br>Rainbow smelt | 8,855<br>2,297<br>1,278 | **1.00**<br>Unknown<br>Unknown | New fish passageway | $49,438 | $49,438[b] |
| Species not valued | Hogchoker<br>Bay anchovy<br>Silver hake<br>Atlantic menhaden<br>Windowpane<br>Butterfish<br>Seaboard goby<br>American sand lance | 12,968<br>6,090<br>5,773<br>2,623<br>1,320<br>278<br>0<br>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 |

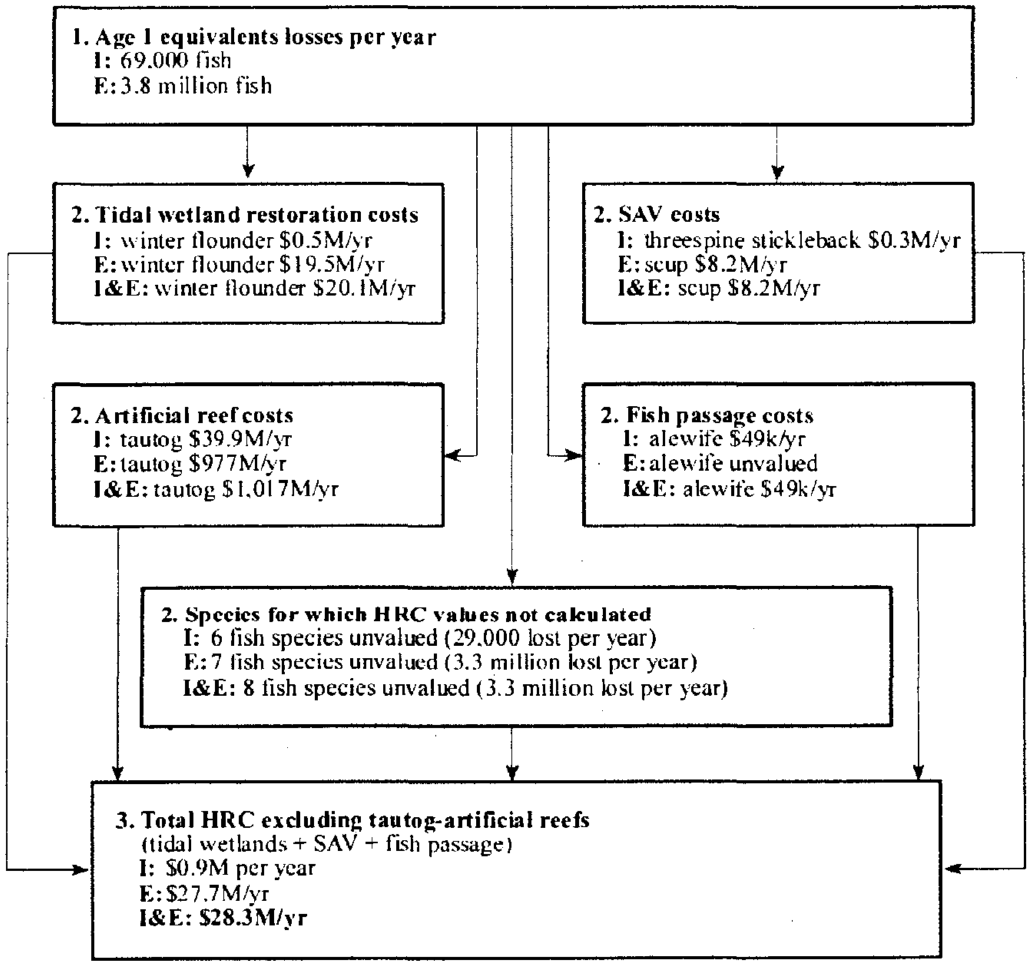
[a] Numbers of units used to calculate costs for each restoration alternative are shown in bold.
[b] Anadromous fish passageways must be implemented in whole units.

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

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



## 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.

CHAPTER CONTENTS



## 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.

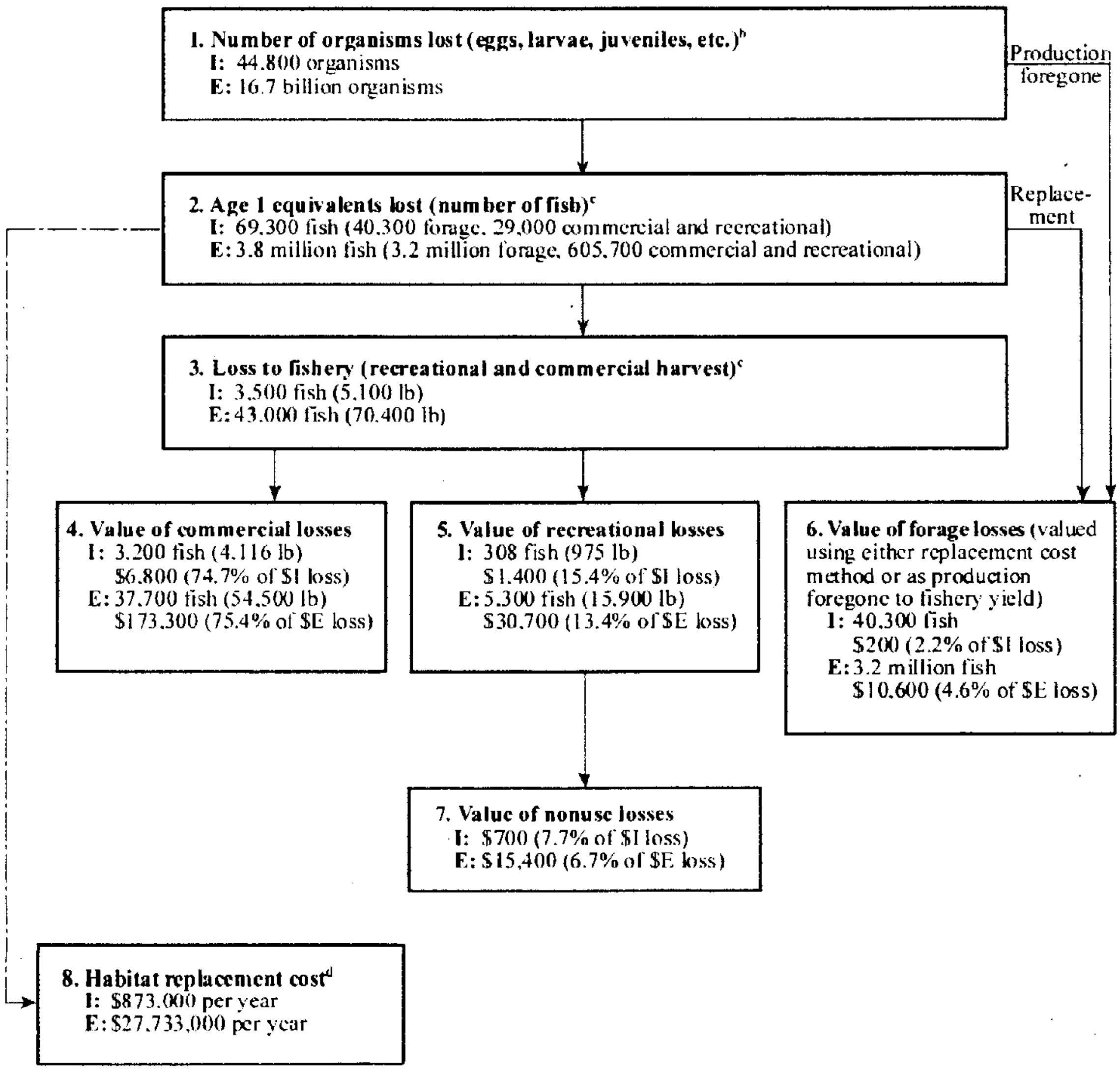
**Table F6-2: Summary of Current Economic Losses and Benefits of a Range of Potential I&E Reductions at Brayton Point Station ($2000)**

| | | 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)**

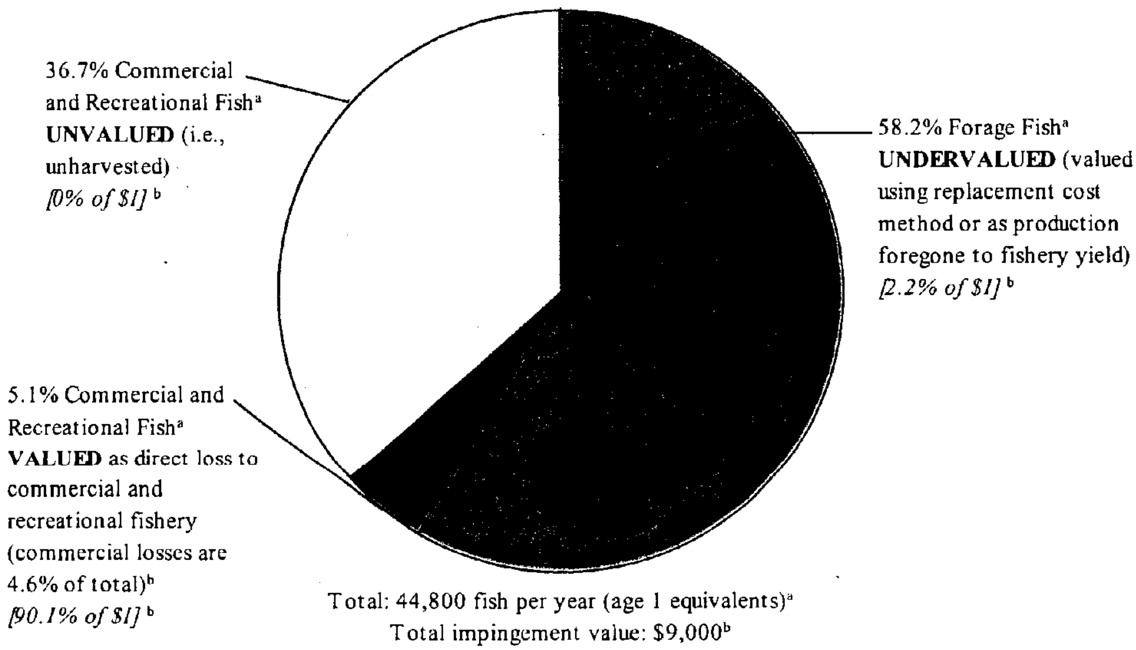
| | | Impingement | Entrainment | Total |
|---|---|---|---|---|
| 20% reduced impingement and 40% reduced entrainment | low | $2,000 | $92,000 | $94,000 |
| | high | $175,000 | $11,093,000 | $11,268,000 |
| 50% reduced impingement and 60% reduced entrainment' | low | $5,000 | $138,000 | $143,000 |
| | 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]



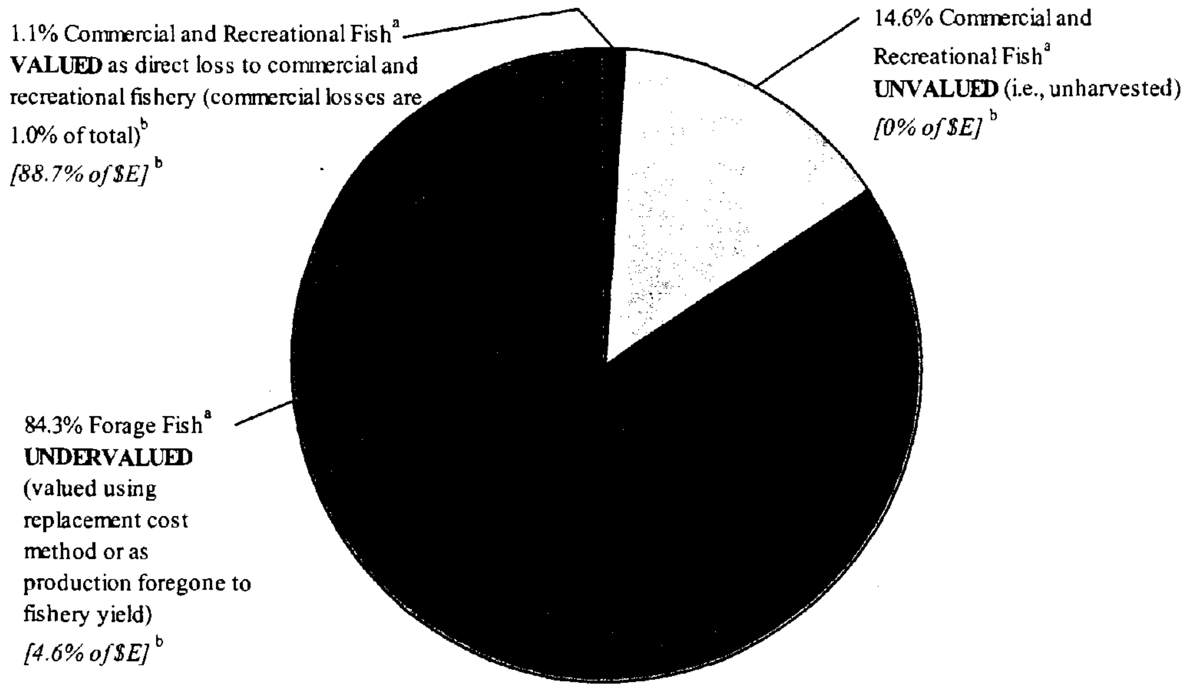

[a] All dollar values are the midpoint of the range of estimates.
[b] From Table F3-10 of Chapter F3.
[c] From Tables F4-2, F4-3, F4-9, and F4-10 of Chapter F4.
[d] Excluding estimated HRC costs for artificial reef emplacement, as discussed in Chapter F5.
Note: Species with I&E <1 percent of the total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

Figure B6-2: Brayton Point: Distribution of Impingement Losses by Species Category and Associated Economic Values




[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 $1 loss.

Figure F6-3: Brayton: Distribution of Entrainment Losses by Species Category and Associated Economic Values




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: $(4.0 \times 10^{-6})$*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: $(3.79 \times 10^{-6})$*Length(mm)$^{3.17}$ = 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: $(2.6 \times 10^{-5})$*Length(mm)$^{2.96}$ = 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.

CHAPTER CONTENTS



## 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).

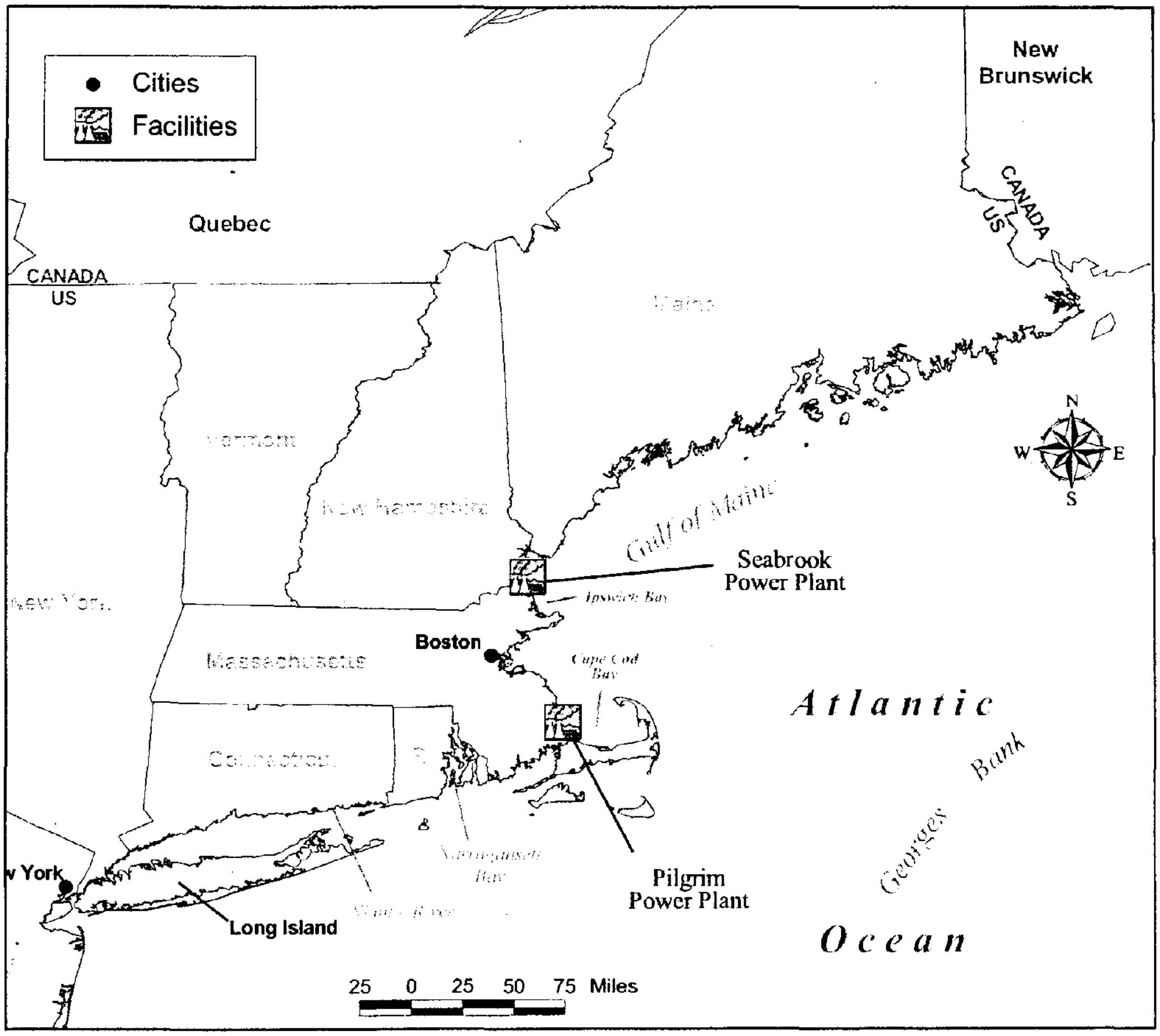
**Pilgrim** began operation as a regulated utility plant. In July 1999, Entergy Nuclear acquired the plant from Boston Edison. Entergy Nuclear is a division of Entergy Corporation. Entergy Corporation is a global, competitive energy company with 14,100 employees worldwide and a total generating capacity 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).

[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]

[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 (*Rosà 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 | Year | | | | | | | | | | | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | |
| 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 | Year | | | | | | | | | | | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | |
| 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 | | | | | 442 | 256 | 256 | 1,065 | 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 | Year | | | | | | | | | | | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | |
| 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 | | | | 180 | | | | 78,780 |
| Amberjack | | | | 22 | 18 | 49 | 1 | 1 | | 48 | | 139 |
| Argentines | | | | | | | | | | 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 | | | | | 3 | | | 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 | | 806 | 1,148 | | 311 | 78,451,228 |
| Shark, longfin mako | 129 | 4,736 | 19,998 | | | | 2,548 | | 924 | 92 | | 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 | Year | | | | | | | | | | | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | |
| 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 | 1,542 | | | 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 | 1,000 | 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 | 229,425,468 | 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 | Year | | | | | | | | | | | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | |
| Alewife | $1,976 | $2,496 | $2,244 | $2,268 | | | | $360 | | | | $9,344 |
| Amberjack | | | | $4 | $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 | | $204 | | | $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 | | $14 | $13 | $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 | Year | | | | | | | | | | | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | |
| Shark, night | | | | | | $115 | | $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 | | | $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 |

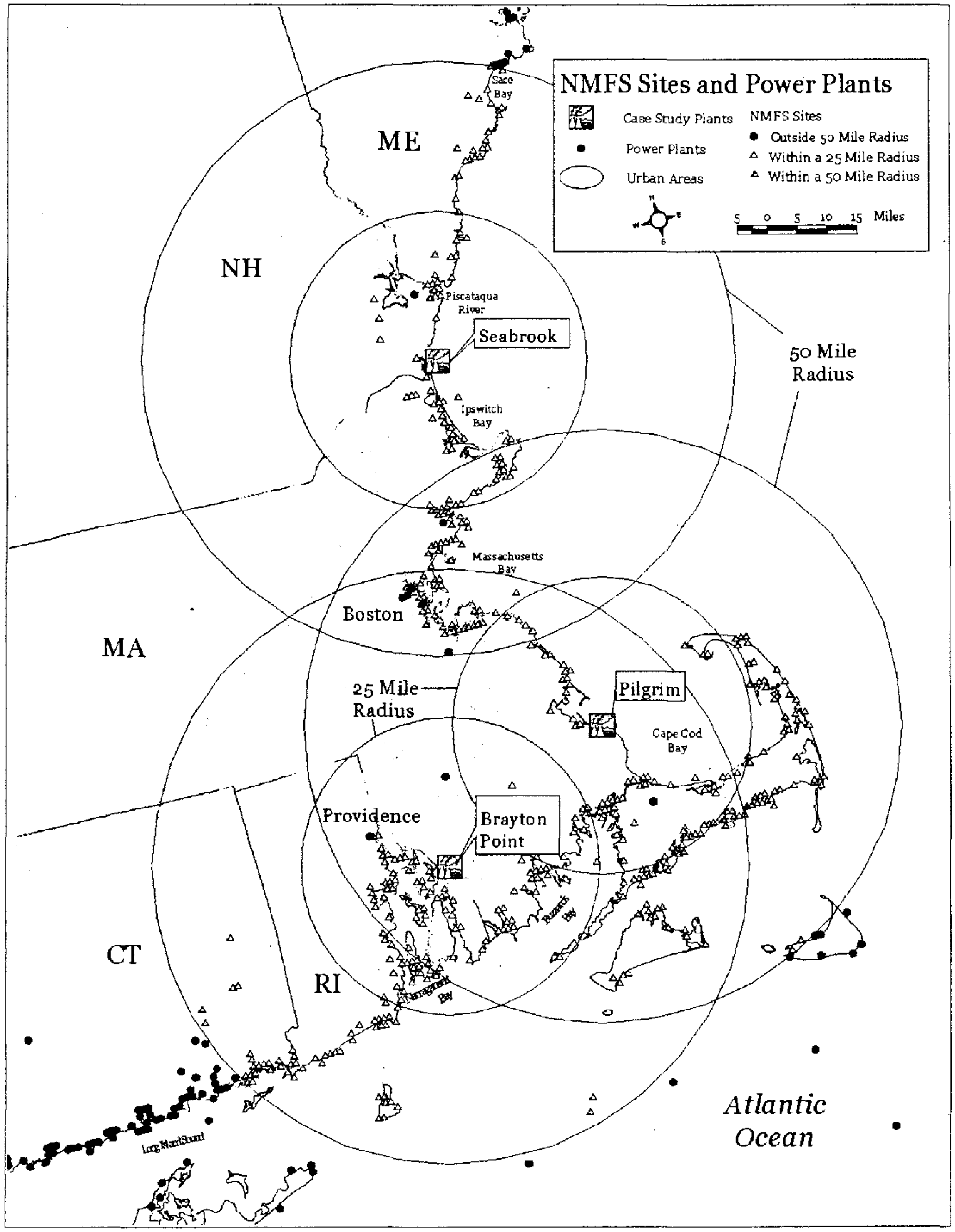
[a] The total number of sites is less than the sum from each power plant because some sites are within 50 miles of both the Pilgrim and Brayton Point plants.

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

CHAPTER CONTENTS



### 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.

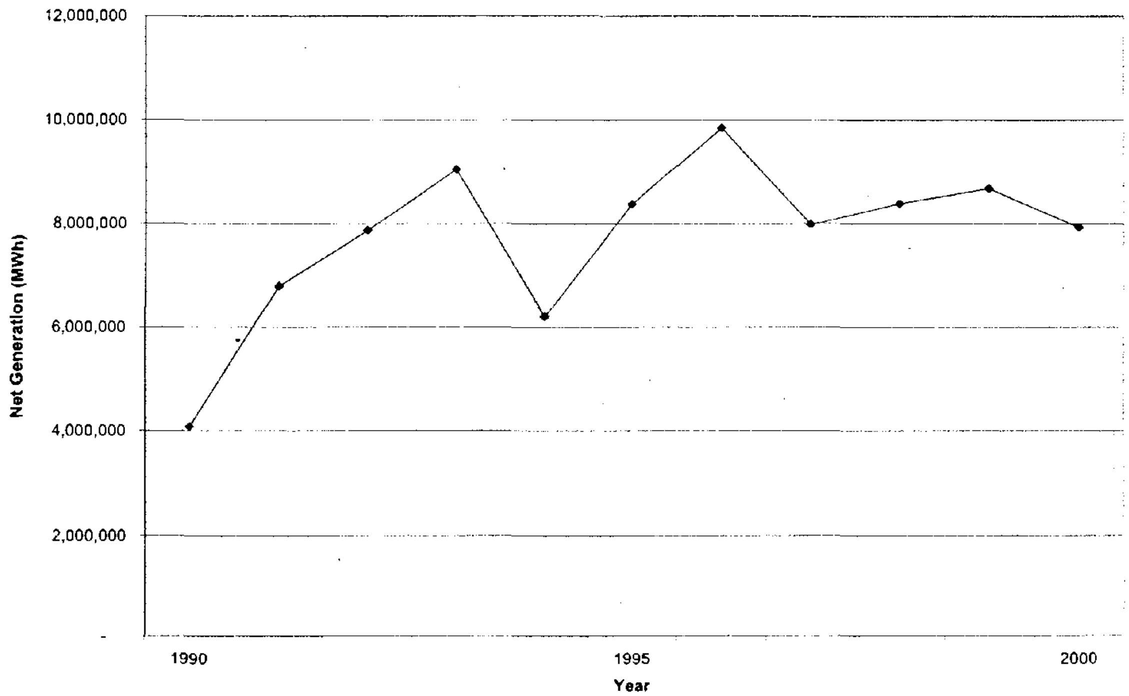
Table G2-1: Generator Detail of the Seabrook Plant (1999)

| 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.

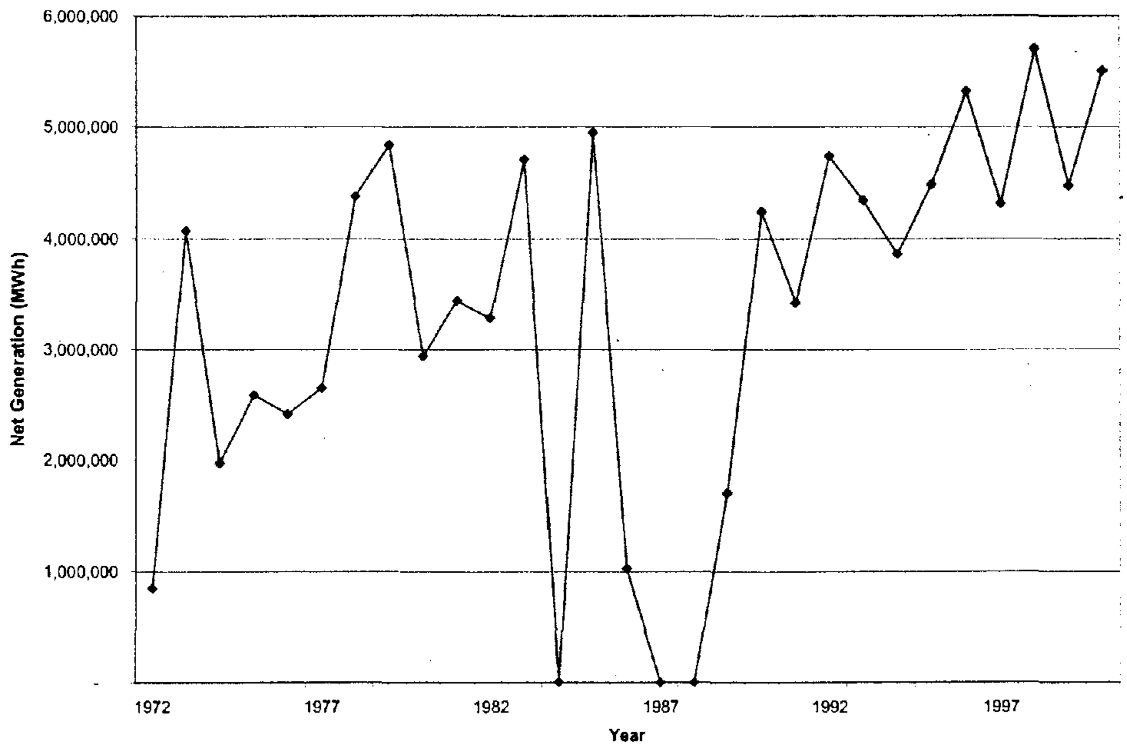
Table G2-2: Pilgrim Generator Characteristics (1999)

| 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.

CHAPTER CONTENTS



## 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 | 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

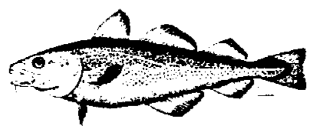
Fishery Management Council's Northeast Multispecies Management Plan. The goal of the plan is to reduce fishing mortality to levels which will allow stocks to rebuild.

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)***

**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]

**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:**

*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).

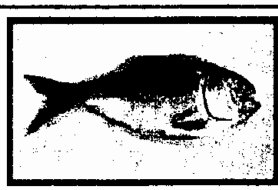
Atlantic menhaden spawn year round at sea and in larger bays. In waters from Maine to Massachusetts, spawning takes place from May to October (Scott and Scott, 1988). The majority of spawning occurs over the inner continental shelf, with lesser activity in bays and estuaries (Able and Fahay, 1998).

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).

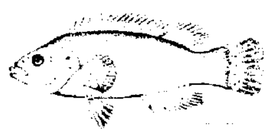
In Cape Cod Bay, cunner spawn close to shore from mid-March until mid-July (Lawton et al., 2000). In more northern areas the spawning season lasts from May to September. Spawning peaks in waters near Woods Hole, Massachusetts, during the first three weeks of June (Lawton et al., 2000). Males and females 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.

[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 G3-2: 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; 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 G3-4: 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 G3-7: 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 G3-8: 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.
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 G3-9: 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 | NA | NA | NA | NA | NA | NA |
| 1977 | NA | NA | NA | NA | NA | NA | NA | NA | 2,735 | 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 | 20,733 | NA | NA | NA | NA | NA |
| 1980 | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA |
| 1981 | NA | NA | NA | NA | NA | NA | NA | NA | 83,346 | NA | NA | NA | NA | NA |
| 1982 | NA | NA | NA | NA | NA | NA | NA | NA | 1,696 | NA | NA | NA | NA | NA |
| 1983 | NA | NA | NA | NA | NA | NA | NA | NA | 1,114 | NA | NA | NA | NA | NA |
| 1984 | NA | NA | NA | NA | NA | NA | NA | NA | 185 | 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 | NA | NA | NA | NA | NA | NA |
| 1988 | NA | NA | NA | NA | NA | NA | NA | NA | 586 | NA | NA | NA | NA | NA |
| 1989 | NA | NA | NA | NA | NA | NA | NA | NA | 1,701 | 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 | 0 | 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 | 10 | 127 | 962 | 6,116 |

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 | Bluefish | Butterfish | Cunner | Flying Gurnard | Fourbeard Rockling | Grubby | Hogchoker | Little Skate | Lumpfish | Northern Kingfish | Northern Pipefish | Northern Puffer | Orange Filefish | Pearlside | 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 Scad | 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.
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 | 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.
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 G3-11: 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 | NA | NA | NA | NA | NA | NA |
| 1988 | NA | NA | NA | NA | NA | NA | 1,054 | NA | NA | NA | NA | NA |
| 1989 | NA | NA | NA | NA | NA | NA | 3,060 | 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/Scabrook-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 G3-12: 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/scodc/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 | NA | NA | NA | NA | NA | NA | NA | NA |
| 1978 | NA | NA | 297 | 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 G3-13: 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 G3-16: 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.

CHAPTER CONTENTS



## 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 |

\\alexandria\project\INTAKE\Seabrook-Pilgrim\Science\scode\seabrook\tables.output.90.98.no.mussel\flowchart.IMP.NEW.xls

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 |

\\alexandria\project\INTAKE\Seabrook-Pilgrim\Science\scode\pilgrim\tables.output.74.99\flowchart.IMP.NEW.csv

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 |

\\alexandria\project\INTAKE\Seabrook-Pilgrim\Science\scode\seabrook\tables.output.90.98.no.mussel\flowchart.ENT.NEW.xls.

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 |

\\alexandria\project\INTAKE\Seabrook-Pilgrim\Science\scode\pilgrim\tables.output.74.99\flowchart.ENT.NEW.csv

# 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 |

\\alexandria\project\INTAKE\Seabrook-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 |

\\alexandria\project\INTAKE\Seabrook-Pilgrim\Science\scode\seabrook\tables.output.90.98.no.mussel\flowchart.ENT.NEW.xls

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 |

\\alexandria\project\INTAKE\Seabrook-Pilgrim\Science\scode\pilgrim\tables.output.74.99\flowchart.IMP.NEW.csv

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 |

\\alexandria\project\INTAKE\Seabrook-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.

**CHAPTER CONTENTS**



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 |
| Searobin | 69 | 3,698 | 3,767 |
| Atlantic cod | 301 | 2,138 | 2,439 |
| Red hake | 229 | 1,545 | 1,774 |
| Lumpfish | 217 | 1,080 | 1,297 |
| Tautog | 201 | 875 | 1,076 |
| Grubby | 879 | NA | 879 |

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

| Species | Impingement | Entrainment | Total |
|---|---|---|---|
| Blueback herring | 703 | NA | 703 |
| Pollock | 33 | 492 | 525 |
| Butterfish | 399 | NA | 399 |
| American plaice | 0 | 221 | 221 |
| Northern pipefish | 118 | NA | 118 |
| Threespine stickleback | 118 | NA | 118 |
| Scup | 114 | NA | 114 |
| Striped killifish | 90 | NA | 90 |
| Little skate | 78 | NA | 78 |
| White perch | 73 | NA | 73 |
| Bay anchovy | 18 | NA | 18 |
| Striped bass | 9 | NA | 9 |
| Bluefish | 2 | NA | 2 |
| Hogchoker | 2 | NA | 2 |
| **Total age 1 eq. finfish losses** | 52,739 | 14,363,013 | 14,415,752 |
| ***Shellfish*** | | | |
| Blue mussel | 15 | 160,000,000,000 | 160,000,000,000[a] |
| **Total age 1 eq. shellfish losses** | 15 | 160,000,000,000 | 160,000,000,000[a] |

[a] Rounded to nearest billion.

## G5-2 Step 2: Identify Habitat Requirements

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

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

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

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

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

## Restore submerged aquatic vegetation

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

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

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

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

*Source:* Boschker, 2001.

## Restore tidal wetlands

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

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

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

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

## Create artificial reefs

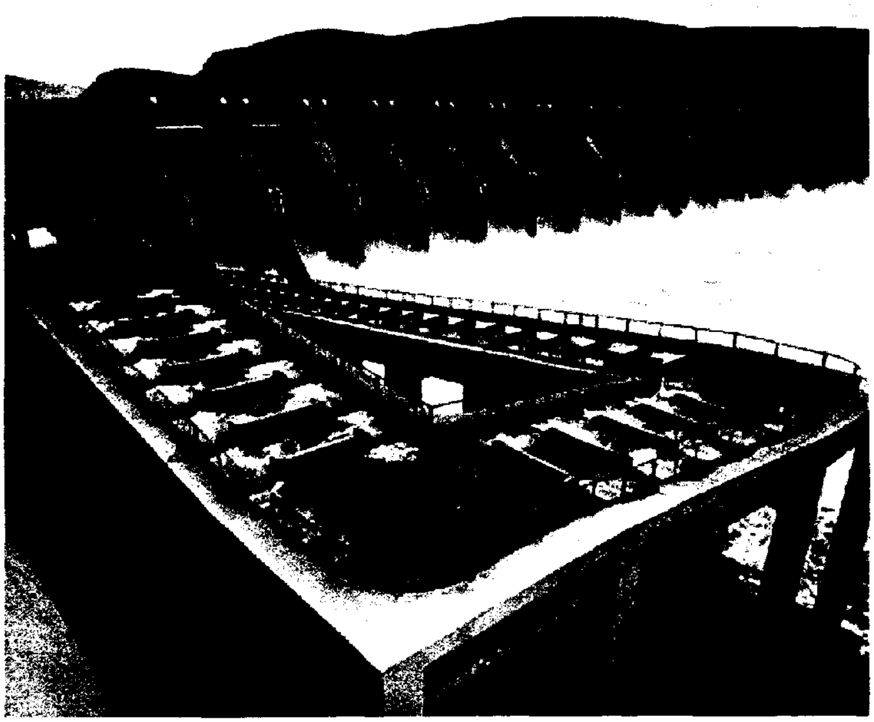
Several species of fish found near the Pilgrim facility use rocky or reef-like habitats with interstices that provide refuge from predators. These habitats can be created artificially with cobbles, concrete, and other suitable materials. Species impinged and entrained at Pilgrim that commonly use reef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

## Improve anadromous fish passageways

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

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

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



*Source:* Pollock, 2001.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

### G5-5.1.1 Species abundance estimates in SAV habitats

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

#### Species abundance in Buzzards Bay SAV

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

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

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

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

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

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

## Species abundance in Rhode Island coastal salt pond SAV

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

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

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

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

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

## Species abundance in Nauset Marsh (Massachusetts) estuarine complex SAV

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

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

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

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

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

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

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

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

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

EPA adjusted sampling-based abundance estimates to account for:

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

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

#### Adjusting for sampling efficiency

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

#### Adjusting sample abundance estimates to age 1 life stages

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

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

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

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

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

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

### Adjusting sampled abundance for differences between restored and undisturbed habitats

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

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

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

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

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

| Species | Source of Initial Species Abundance Estimate | Species Abundance Estimate per 100 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 $m^2$) | | |
|---|---|---|---|---|
| | | Narrow River | Winnapaug Pond | Point Judith Pond |
| Winter flounder | beach seine | 0.32 | 0.21 | 0.21 |

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

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

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

### Sampling efficiency

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

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

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

### Conversion to age 1 life stage

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

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

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

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

### Adjusting for differences between restored and undisturbed habitats

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

### Adjusting sampled abundance for timing and location of sampling

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

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

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

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

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

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

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

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

| Species | Source of Initial Species Density Estimate | Sampling Location and Date[a] | Reported/Calculated Species Density Estimate per 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 | 0.5022 | 1 | 11.90 | 0.12 |
| | Raposa, in press | Galilee Marsh — 1999 | 14.38 | 1.6 | 0.5022 | 1 | 11.90 | 0.97 |
| | **Species average** | | | | | | | **0.19** |
| Grubby | Unknown | | | | | | | |
| Striped killifish | Roman et al., submitted 2000 to *Restoration Ecology* | Sachuest Point — 1997 | 0.70 | 1.6 | 0.5474 | 1 | 18.18 | 0.03 |
| | Roman et al., submitted 2000 to *Restoration Ecology* | Sachuest Point — 1998 | 0.17 | 1.6 | 0.5474 | 1 | 18.18 | 0.01 |
| | Roman et al., submitted 2000 to *Restoration Ecology* | Sachuest Point — 1999 | 0.55 | 1.6 | 0.5474 | 1 | 18.18 | 0.03 |
| | Roman et al., submitted 2000 to *Restoration Ecology* | Sachuest Point — 1998 (lift net) | 0.01 | 1.3 | 0.5474 | 1 | 1.00 | 0.01 |
| | Roman et al., submitted 2000 to *Restoration Ecology* | Sachuest Point — 1999 (lift net) | 0.01 | 1.3 | 0.5474 | 1 | 1.00 | 0.01 |
| | Raposa pers comm 2001 | NERR — Prudence Isl. Coggeshall — July 2000 | 2.40 | 1.6 | 0.5474 | 1 | 19.23 | 0.11 |
| Striped killifish | Raposa pers comm 2001 | NERR — Prudence Isl. Coggeshall — Sept. 2000 | 0.53 | 1.6 | 0.5474 | 1 | 19.23 | 0.02 |
| | Raposa, in press | Galilee Marsh — 1997 | 4.35 | 1.6 | 0.5474 | 1 | 11.90 | 0.32 |
| | Raposa, in press | Galilee Marsh — 1998 | 3.50 | 1.6 | 0.5474 | 1 | 11.90 | 0.26 |

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

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

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

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

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

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

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

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

### G5-5.3.1 Species abundance estimates in artificial reef habitats

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

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

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

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

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

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

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

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

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

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

### Sampling efficiency

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

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

### Conversion to the age 1 equivalent life stage

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

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

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

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

### Adjusting for differences between restored and undisturbed habitats

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

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

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

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

| Species | Source of Initial Species Density Estimate | Species Abundance Estimates (fish/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 $m^2$ of revegetated habitat.

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

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

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

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

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

**Table G5-33: Implementation Unit Costs for SAV Restoration**

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

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

### G5-7.1.2 Monitoring costs

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

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

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

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

### G5-7.1.3 Total submerged aquatic vegetation restoration costs

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

## G5-7.2 Unit Costs of Tidal Wetland Restoration

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

### G5-7.2.1 Implementation costs

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

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

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

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

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

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

---

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

Table G5-35: Salt Marsh Restoration Costs

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

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

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

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

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

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

### G5-7.2.2 Monitoring costs

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

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

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

*Source:* Neckles and Dionne, 1999.

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

### G5-7.2.3 Total tidal wetland restoration costs

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

## G5-7.3 Artificial Reef Unit Costs

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

### G5-7.3.1 Implementation costs

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

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

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

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

### G5-7.3.2 Monitoring costs

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

### G5-7.3.3 Total artificial reef costs

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

## G5-7.4 Costs of Anadromous Fish Passageway Improvements

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

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

### G5-7.4.1 Implementation costs

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

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

### G5-7.4.2 Maintenance and monitoring costs

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

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

### G5-7.4.3 Total fish passageway unit costs

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

## G5-8 Total Cost Estimation

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

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

| 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 |

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

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

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

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

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

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

| Preferred Restoration Alternative | Species Benefitting from the Restoration Alternative | | 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 $m^2$ 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** | $m^2$ 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** | $m^2$ of reef surface area | $24.85 | $170,333 |
| | Cunner | 411 | 70 | | | |
| | Rock gunnel | 77 | Unknown | | | |
| | Radiated shanny | 54 | Unknown | | | |
| | Sculpin spp. | 13 | Unknown | | | |
| Install fish passageways | Alewife | 4,343 | **0.49** | New fish passageway | $49,437.64 | $49,438[b] |
| | Rainbow smelt | 6,885 | Unknown | | | |
| | Blueback herring | 703 | Unknown | | | |
| | White perch | 73 | Unknown | | | |
| Species not valued | Blue mussel | 150 | Unknown for all | Restoration measures unknown — survival and reproduction may be improved by other regional objectives such as improving water quality or reducing fishing pressure if projects can be identified and are permanent improvements. | N/A | N/A |
| | Atlantic herring | 8,836 | | | | |
| | Atlantic menhaden | 6,165 | | | | |
| | Butterfish | 399 | | | | |
| | Windowpane | 284 | | | | |
| | Red hake | 229 | | | | |
| | Lumpfish | 217 | | | | |
| | Scup | 114 | | | | |
| | Little skate | 78 | | | | |
| | Searobin | 69 | | | | |
| | Bay anchovy | 18 | | | | |
| | Atlantic mackerel | 3 | | | | |
| | Fourbeard rockling | 2 | | | | |
| | Hogchoker | 2 | | | | |
| | American plaice | 0 | | | | |
| Total annualized HRC valuation | | | | | | $496,878 |

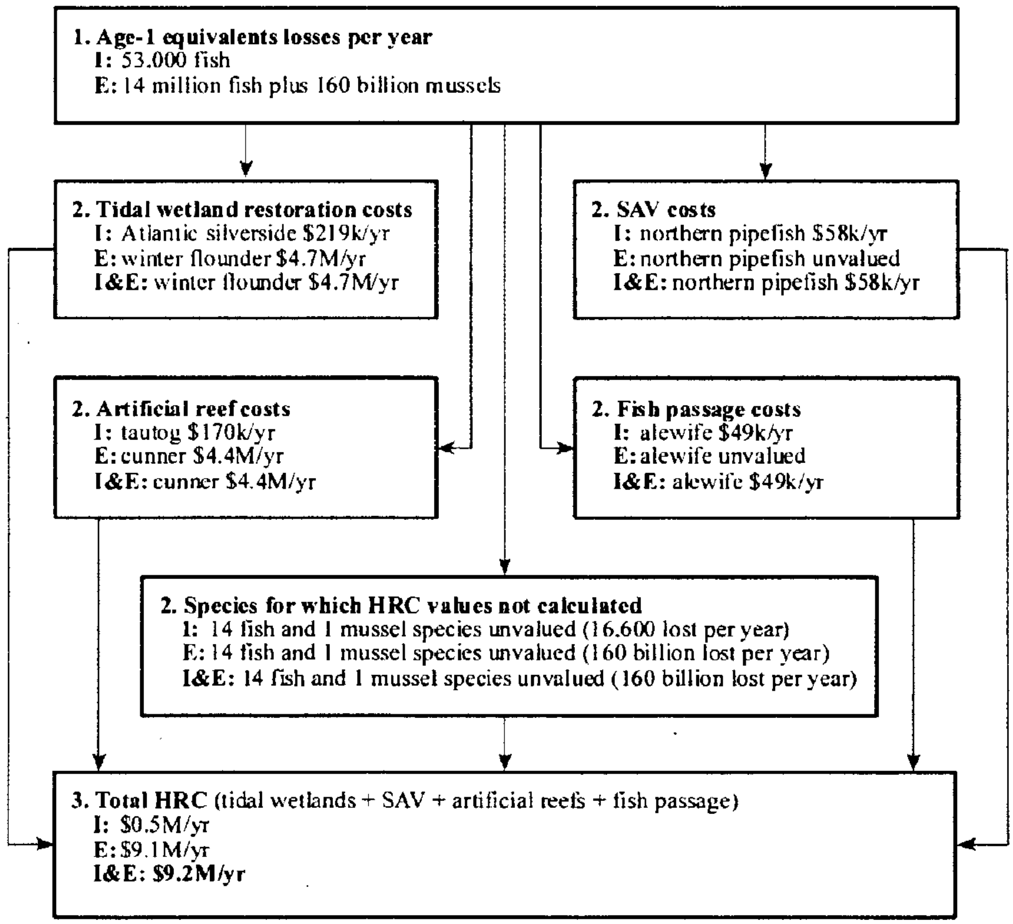
[a] Numbers of units used to calculate costs for each restoration alternative are shown in bold.
[b] Anadromous fish passageways must be implemented in whole units, and increased production data are lacking for most affected anadromous species. Therefore, one new passageway was assumed to be warranted.

| 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 m² 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** | m² 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** | m² 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 arc 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 |

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

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

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



## G5-9 CONCLUSIONS

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

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

# 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.

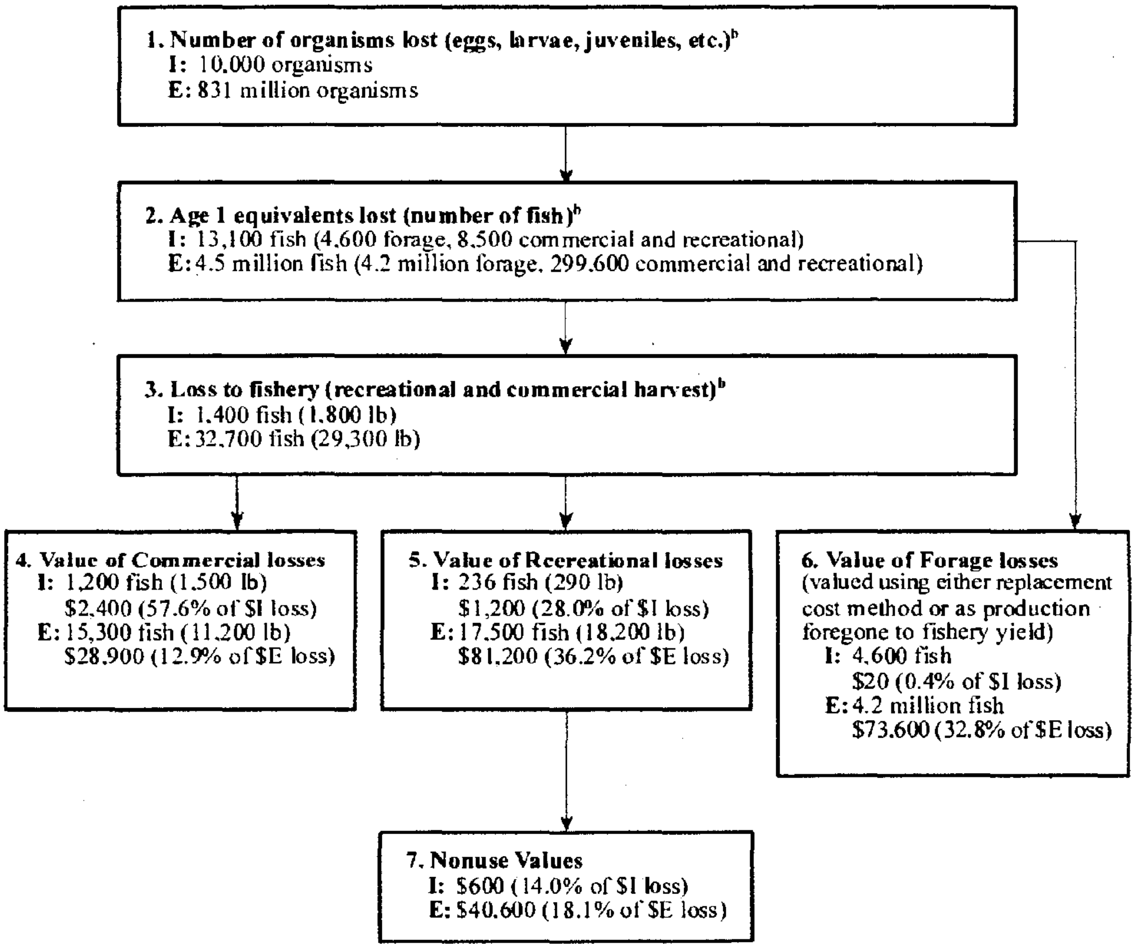
CHAPTER CONTENTS



## G6-1 Overview of I&E and Associated Economic Values

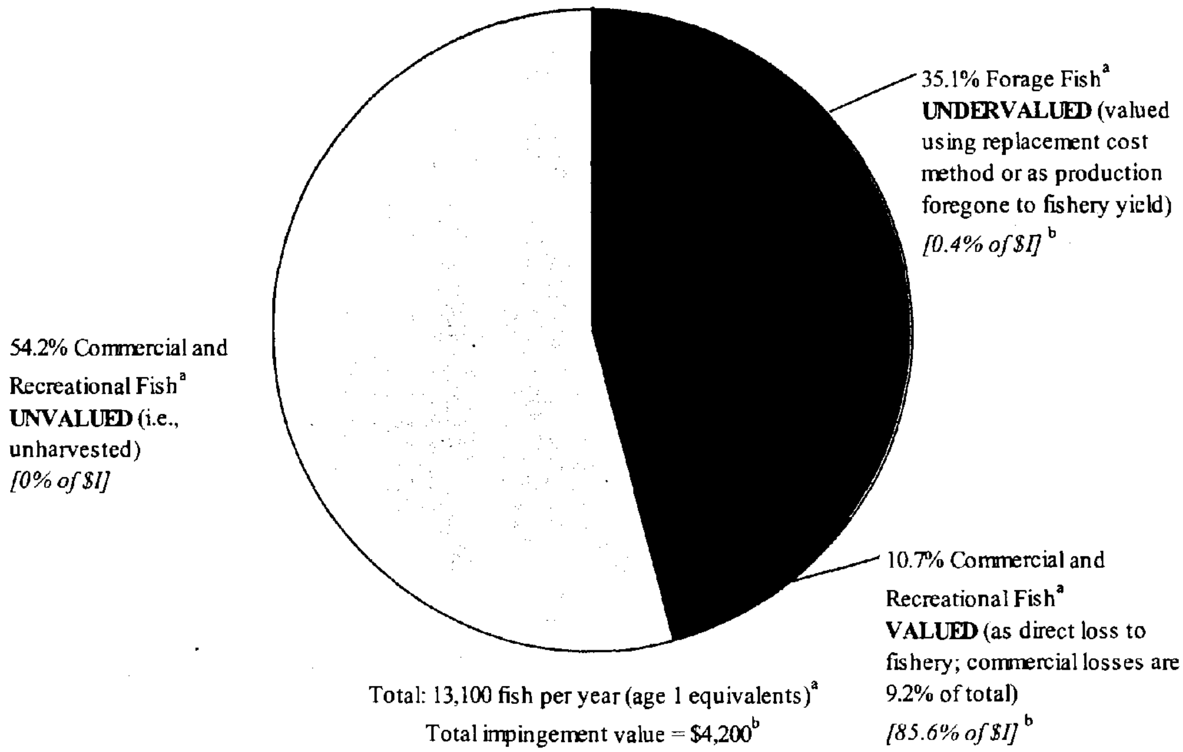
The flowchart in Figure G6-1 summarizes how economic values of I&E losses at Seabrook were derived from the I&E estimates discussed in Chapter G3. Figures G6-2 and G6-3 indicate the distribution of Seabrook's I&E losses by species category and associated economic values. Figures G6-4 through G6-6 present 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)[a]



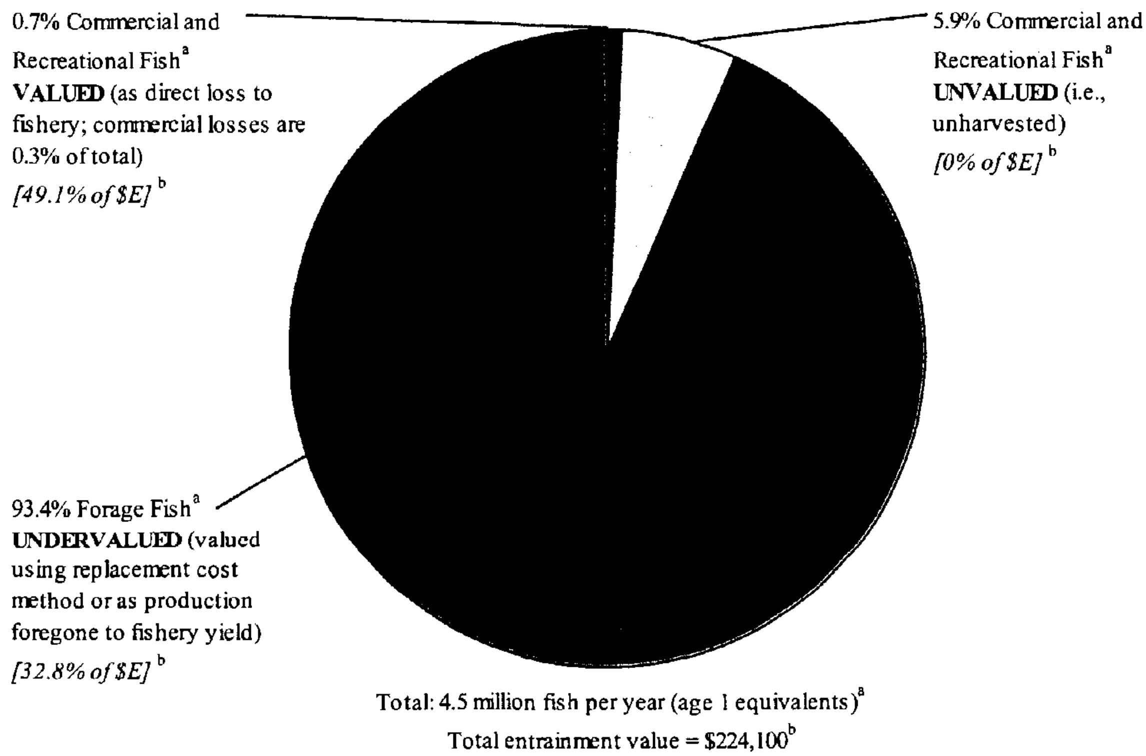

[a] All dollar values are the midpoint of the range of estimates.
[b] From Tables G4-2, G4-4, G4-15 and G4-16 of Chapter G4.
Note: Species with I&E <1% of the total I&E were not valued.

Figure G6-2: Seabrook: Distribution of Impingement Losses by Species Category



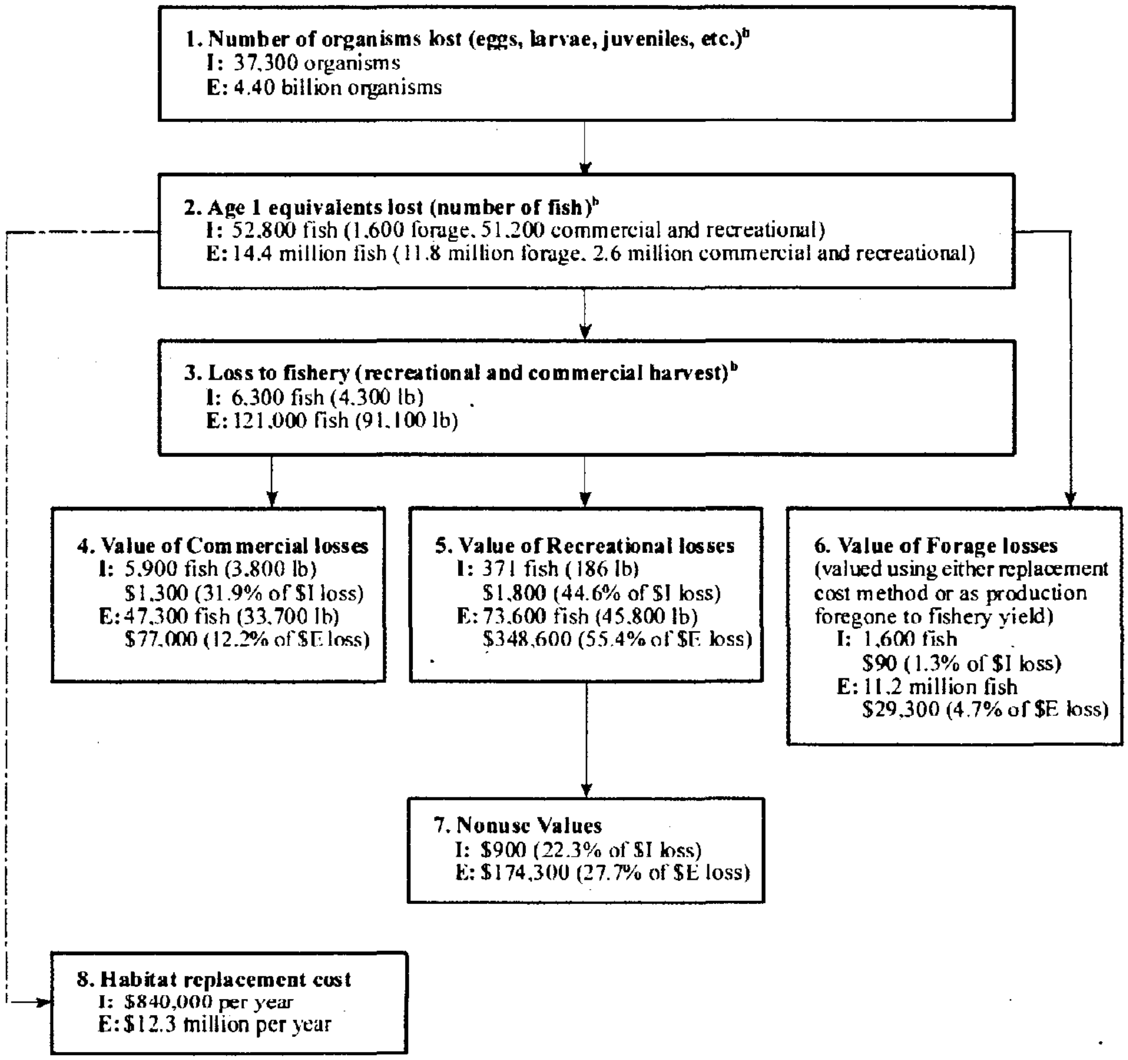

[a] Impacts shown are to age 1 equivalent fish, except impacts to the commercially and recreationally harvested fish include impacts for all ages vulnerable to the fishery.
[b] Midpoint of estimated range. Nonuse values are 14.0% of total estimated $I loss.

Figure G6-3: Seabrook: Distribution of Entrainment Losses by Species Category



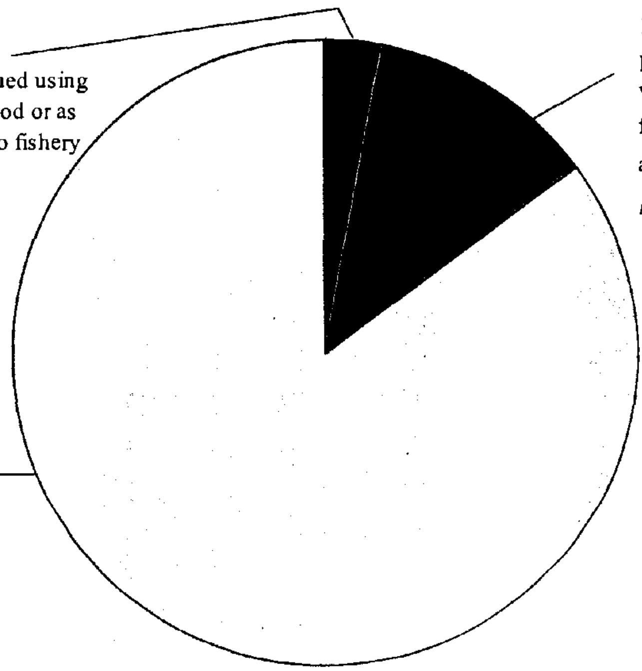

[a] Impacts shown are to age 1 equivalent fish, except impacts to the commercially and recreationally harvested fish include impacts for all ages vulnerable to the fishery.
[b] Midpoint of estimated range. Nonuse values are 18.1% of total estimated $E loss.

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]




[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.

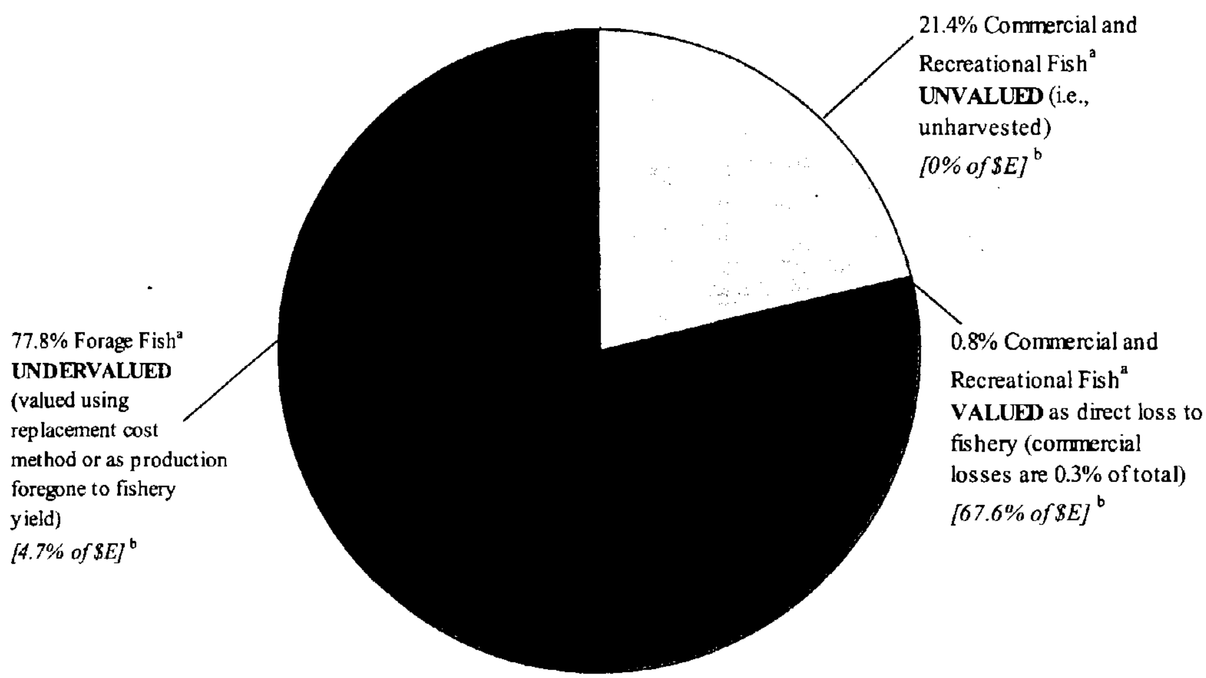
Figure G6-5: Pilgrim: Distribution of Impingement Losses by Species Category and Associated Economic Values




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




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: $(3.2 \times 10^{-7})$*Length(mm)$^{3.491}$ = 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: $(8.85 \times 10^{-6})$*Length(mm)$^{3.031}$ = 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: $(1.22\times10^{-6})*\text{Length(mm)}^{3.328}$ = 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: $(3.039 \times 10^{-6})*\text{Length(mm)}^{3.18} = \text{weight(g)}$ (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: $(6.02\times10^{-6})$*Length(mm)$^{3.216}$ = 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: $(5.691\times10^{-6})$*Length(mm)$^{3.023}$ = 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: $(1.749 \times 10^{-5}) * \text{Length(mm)}^{2.77} = \text{weight(g)}$ (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: $(3.6\times10^{-6})*\text{Length(mm)}^{3.26}$ = weight(g) (Froese and Pauly, 2001).
[g] Length from Able and Fahay (1998).
[h] Length from Scott and Scott (1988).

| 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: $(6.0\times10^{-6})*\text{Length(mm)}^{3.22}$ = 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: $(12.74\times10^{-6})*\text{Length(mm)}^{3.106}$ = 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: $(1.034\times10^{-5})*\text{Length(mm)}^{3.003}$ = 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: $(1.947\times10^{-4})*\text{Length(mm)}^{2.658}$ = 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: $(8.32\times10^{-6})*\text{Length(mm)}^{2.972}$ = 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: $(6.755 \times 10^{-5})*\text{Length(mm)}^{2.939} = \text{weight(g)}$ (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: $(9.407 \times 10^{-6})*\text{Length(mm)}^{2.66} = \text{weight(g)}$ (Froese and Pauly, 2001).
[f] Length from Scott and Scott (1988).
[g] Length assumed based on Scott and Scott (1988).

**Table G1-21: 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: $(6.894 \times 10^{-6}) * \text{Length(mm)}^{3.048} = \text{weight(g)}$ (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: $(4.125 \times 10^{-6}) * \text{Length(mm)}^{3.018} = \text{weight(g)}$ (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: $(3.903 \times 10^{-5}) * \text{Length(mm)}^{2.81} = \text{weight(g)}$ (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: $(2.692 \times 10^{-6})$*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] |
| Larvac | 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: $(4.125 \times 10^{-6})$*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: $(1.034\text{x}10^{-5})*\text{Length(mm)}^{3.003}$ = 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: $(1.034\times10^{-5})*\text{Length(mm)}^{3.003}$ = 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 | 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: $(2.6\times10^{-5})*\text{Length(mm)}^{2.96} = \text{weight(g)}$ (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: $(3.318\times10^{-5})*\text{Length(mm)}^{2.94} = \text{weight(g)}$ (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: $(2.10\times10^{-6})*\text{Length(mm)}^{3.00} = \text{weight(g)}$ (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: $(2.10\times10^{-6})*\text{Length(mm)}^{3.00}$ = 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: $(6.591\times10^{-6})*\text{Length(mm)}^{3.109} = \text{weight(g)}$ (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).