Status Review for Anadromous Atlantic Salmon (*Salmo salar*) in the United States

Atlantic Salmon Biological Review Team

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Table of Contents

Section 1: Executive Summary **5**

Section 2: Introduction and Background **6**

Section 3: Biological Information **8**

3.1 Life History *8*
3.1.1 Freshwater Habitat 9
3.1.2 Marine Habitat 13

3.2 Stock Structure *15*

3.3 Ecological Setting *17*
3.3.1 Atlantic Salmon as Prey 18
3.3.2 Atlantic Salmon as Predators 19
3.3.3 Nutrient Cycling 19
3.3.4 Other Co-evolutionary Relationships 20
3.3.5 Habitat Availability, Accessibility, and Metapopulation Structure 21

Section 4: Historic Distribution and Abundance **22**

Section 5: Artificial Propagation **25**

5.1 Hatcheries and Feeding Stations in Maine *25*

5.2 Stocking Strategies and Numbers Stocked *26*
5.2.1 Juvenile Stocking 26
5.2.2 Adult Stocking and Transfers 27
5.2.3 Current Stocking Strategies 27
5.2.4 Broodstock Sources Through Time 28

5.3 Landlocked Atlantic Salmon Stocking in Maine *33*

5.4 Summary of Artificial Propagation *33*

Section 6: Consideration as a "Species" Under the ESA **34**

6.1 Distinct Population Segment Analysis Background *34*
6.1.1 Biological Background 34
6.1.2 Policy Background 34

6.2 Analysis of DPS Structure Within the U.S. *36*
6.2.1 Long Island Sound 41
6.2.2 Central New England 41
6.2.3 Gulf of Maine 42
6.2.4 Summary 43

6.3 Assessment of the Gulf of Maine DPS *44*
6.3.1 Discreteness 44
6.3.2 Biological and Ecological Significance 56
6.3.3 The Penobscot Population 58
6.3.4 Hatchery Populations 59

6.4 Ramifications for Restoration Programs Outside the Historic Range of the GOM DPS *60*

Section 7: Current Distribution and Abundance ... 61

7.1 Adult Abundance ... 61

7.2 Juvenile Abundance ... 65
7.2.1 Rivers Without Large Scale Stocking Programs ... 65
7.2.2 Rivers With Large Scale Stocking Programs ... 67
7.2.3 Smolt Abundance ... 68

7.3 Conservation Status and Likelihood of Extinction ... 68

Section 8: Listing Factor Analysis ... 74

8.1 Present or Threatened Destruction, Modification, or Curtailment of Habitat or Range ... 74
8.1.1 Elimination or Degradation of Spawning and Rearing Habitat ... 75
8.1.2 Loss of Habitat Complexity and Connectivity ... 85
8.1.3 Degradation of Water Quality ... 99
8.1.4 Alteration of Water Temperatures ... 113

8.2 Overutilization for Commercial, Recreational, Scientific, or Educational Purposes ... 115
8.2.1 Commercial Fisheries ... 115
8.2.2 Recreational Fisheries ... 117
8.2.3 Illegal In-River Harvest of Adult Atlantic Salmon ... 121
8.2.4 By-catch of Atlantic Salmon in State Recreational and Commercial Fisheries ... 122
8.2.5 Native American Subsistence Fisheries ... 122
8.2.6 Impacts of Scientific Activities ... 123
8.2.7 Educational Uses ... 129

8.3 Predation, Disease, and Competition ... 129
8.3.1 Predation ... 129
8.3.2 Disease ... 135
8.3.3 Competition ... 142

8.4 Inadequacy of Existing Regulatory Mechanisms ... 146
8.4.1 International, National and State Laws, Treaties and Agreements ... 146
8.4.2 Interstate and Interagency Committees ... 160
8.4.3 State Regulations ... 160
8.4.4 Summary of Inadequate Regulatory Mechanisms ... 163

8.5 Other Natural or Manmade Factors Affecting the Continued Existence of the GOM DPS ... 168
8.5.1 Artificial Propagation ... 168
8.5.2 Aquaculture ... 171
8.5.3 Marine Survival ... 174
8.5.4 Ecosystem Function ... 178

Section 9: Conclusion ... 180

Section 10: References ... 181

Section 11: Appendices ... 232

Section 1: Executive Summary

This Status Review presents the findings of the 2005 Atlantic Salmon Biological Review Team (BRT). The 2005 BRT has defined the Gulf of Maine Distinct Population Segment (GOM DPS) of Atlantic salmon (*Salmo salar*) based upon genetic, life history, and zoogeographic information. The GOM DPS is comprised of all anadromous Atlantic salmon whose freshwater range occurs in the watersheds from the Androscoggin northward along the Maine coast to the Dennys, including all associated conservation hatchery populations used to supplement natural populations; currently, such populations are maintained at Green Lake and Craig Brook National Fish Hatcheries. Excluded are those fish raised in commercial hatcheries for aquaculture. This designation largely coincides with the designation proposed by previous BRTs except in the case of large rivers (i.e., Androscoggin, Kennebec above the site of the former Edwards Dam, and Penobscot above the site of the former Bangor Dam). The large rivers were excluded from previous determinations because of an inadequacy of available genetic data to evaluate these populations relative to the small coastal rivers. The 1999 BRT considered the possibility that Atlantic salmon populations within these larger rivers may have been subject to different selection pressures resulting in different adaptations and genetic structure unique to these large river systems. This "large river hypothesis" was re-examined in light of recent genetic information specific to these populations as well as other populations outside the range of the DPS defined in 2000. Based on the best scientific data available, the 2005 BRT concluded that the salmon currently inhabiting the larger rivers are genetically similar to those found in the coastal rivers of Maine (e.g., Narraguagus) and have similar life histories. Further, the populations inhabiting the large and small rivers in the geographic range of the GOM DPS differ genetically and in important life history characteristics from Atlantic salmon in adjacent portions of Canada. When considered together, the populations inhabiting the large and small coastal rivers clearly meet the both the discreteness and significance criteria of the DPS Policy.

Present abundance levels of the GOM DPS are substantially lower than historic levels. Fewer than 1,500 adults have returned to spawn each year since 1998. Population Viability Analysis (PVA) was used to estimate the probability of extinction for the GOM DPS. Depending on the quasi-extinction threshold (QET) chosen, the likelihood of extinction ranges from 19% to 75% within the next 100 years, even with the continuation of current levels of hatchery supplementation.

The 2005 BRT examined the five statutory ESA listing factors relative to the GOM DPS: (1) the present or threatened destruction, modification, or curtailment of its habitat or range; (2) overutilization for commercial, recreational, scientific, or educational purposes; (3) disease or predation; (4) the inadequacy of existing regulatory mechanisms; and (5) other natural or manmade factors affecting its continued existence. Each of the five listing factors is at least partly responsible for the present low abundance of the GOM DPS.

Section 2: Introduction and Background

The Endangered Species Act (ESA; 16 U.S.C. 1531 *et. seq.*) defines an endangered species as one "in danger of extinction throughout all or a significant portion of its range" and a threatened species as one "likely to become endangered in the foreseeable future throughout all or a significant portion of its range." Section 4(b)(1)(a) of the ESA provides that the Secretaries of the Interior and of Commerce shall make listing determinations solely on the basis of the best scientific and commercial data available, after conducting a review of the status of the species and after taking into account those efforts being made by any state or foreign nation to protect such species. A species may be determined to be threatened or endangered because of any of the following factors: (1) the present or threatened destruction, modification, or curtailment of its habitat or range; (2) overutilization for commercial, recreational, scientific, or educational purposes; (3) disease or predation; (4) the inadequacy of existing regulatory mechanisms; and (5) other natural or manmade factors affecting its continued existence (ESA Section 4(a)(1)).

The ESA of 1973, as amended, originally defined species as "any subspecies of fish or wildlife or plants and any other group of fish and wildlife of the same species or smaller taxa in common spatial arrangement that interbreed when mature." In 1978, the ESA was amended and the above definition of a species was modified to include any subspecies of fish, wildlife, or plants, and any distinct population segment (DPS) of any vertebrate which interbreeds when mature. In 1996, the U.S. Fish and Wildlife Service (USFWS) and the National Oceanic and Atmospheric Administrations' National Marine Fisheries Service (NMFS; collectively "the Services") adopted the Policy Regarding the Recognition of Distinct Vertebrate Population Segments Under the Endangered Species Act. This policy was adopted by the Services to clarify how to interpret "distinct population segment of any species of vertebrate fish and wildlife" when making a listing or delisting decision, or reclassifying a species (61 FR 4722).

In 1991, the USFWS designated Atlantic salmon in five rivers in "Downeast" Maine (the Narraguagus, Pleasant, Machias, East Machias and Dennys Rivers) as Category 2 candidate species under the ESA. Category 2 candidate species comprised taxa for which information in the possession of the USFWS indicated that a listing proposal might be appropriate, but for which available data on biological vulnerability and threats was not currently sufficient to support a proposed rule. The USFWS redefined "candidate" and abolished the Category 2 designation in 1996.

The USFWS and NMFS received identical petitions in October and November of 1993 from RESTORE: The North Woods, Biodiversity Legal Foundation, and Jeffrey Elliot to list the Atlantic salmon throughout its historic range in the contiguous United States under the ESA. The Services published a notice on January 20, 1994 that the petition presented substantial scientific information indicating that a listing may be warranted and requested comments from the public.

The Services concurrently initiated a study of the status of U.S. Atlantic salmon in relation to the ESA. In 1995, a Biological Review Team (BRT) consisting of members

from each Service was appointed to review the petition, prepare a formal Status Review, and make recommendations as to the appropriate joint agency petition response. The 1995 BRT evaluated the status of Atlantic salmon by analyzing trends in historic and recent abundance and spawner escapement goals. The Status Review was published in January 1995 and indicated that the DPS, comprised of Atlantic salmon populations in seven rivers (the Dennys, East Machias, Machias, Pleasant, Narraguagus, Ducktrap and Sheepscot Rivers), was in danger of extinction. The Status Review was submitted for peer review and made available for public review. On September 29, 1995, after reviewing state and foreign efforts to protect the species, the Services proposed to list the seven rivers DPS as a threatened species under the ESA (60 FR 50530). The proposed rule contained a special rule under Section 4(d) of the ESA, which allowed for a State plan, approved by the Services, to define the manner in which certain activities could be conducted without violating the ESA. The 1995 Status Review and subsequent listing action were completed prior to the adoption of the Services' DPS policy in 1996.

Following the issuance of the proposed rule, the Governor of Maine issued an Executive Order on October 20, 1995, appointing the Maine Atlantic Salmon Task Force, and charged that Task Force with preparing a conservation plan for the protection and recovery of Atlantic salmon in the seven rivers. In the fall of 1996, the State held public hearings on the Conservation Plan and solicited and accepted comments from the public concerning the content of the Conservation Plan. In March of 1997, the Maine Atlantic Salmon Task Force submitted the Atlantic Salmon Conservation Plan for Seven Maine Rivers (Conservation Plan) to the Services.

The Services reopened the public comment period for the proposed threatened designation on May 23, 1997, to obtain public comments on the Conservation Plan and other new information which included adult returns, redd counts, fry stocking, habitat assessments, commercial fishing agreements, and management measures (62 FR 28413). On December 18, 1997, following review of information submitted by the public and current information on population status, the Services withdrew the proposed rule to list the seven rivers DPS of Atlantic salmon as threatened under the ESA (62 FR 66325). In the withdrawal notice, the Services redefined the species under analysis as the Gulf of Maine (GOM) DPS and determined that it was not likely to become endangered in the foreseeable future, due to ongoing and planned management actions under the Conservation Plan. The notice stated the Services' commitment to make the state's annual reports on implementation of the Conservation Plan available to the public for review and comments and also outlined circumstances under which the process for listing the GOM DPS of Atlantic salmon under the ESA would be reinitiated.

The Governor of Maine issued Executive Orders on December 15, 1997 and April 23, 1997 which charged all state agencies with implementing the Conservation Plan. On December 15, 1998, the Services also entered into a Statement of Cooperation with Maine in support of implementation of the Conservation Plan. The Services received Maine's 1998 Annual Progress Report on Conservation Plan implementation in January 1999. In the January 20, 1999 Federal Register notice (64 FR 3067), the Services requested assistance from the public in determining whether the protective measures in

place, including the provisions of the Conservation Plan, remained adequate to protect the species in light of current knowledge.

The BRT was reconvened to update the 1995 Status Review for Atlantic salmon and to conduct a comprehensive review of protective measures implemented in the Conservation Plan. The 1999 Status Review was made available to the public October 19, 1999 (64 FR 56297). On November 17, 1999, the Services published a proposed rule to list the GOM DPS as endangered. The GOM DPS was defined as all naturally reproducing wild populations of Atlantic salmon, having historical river-specific characteristics found north of and including tributaries of the lower Kennebec River to, but not including the mouth of the St. Croix River at the United States-Canada border and the Penobscot River above the site of the former Bangor Dam. Populations which met these criteria were found in the following rivers: Dennys, East Machias, Machias, Pleasant, Narraguagus, Sheepscot, Ducktrap, and Cove Brook.

After consideration of extensive written and oral public comments, and those of three scientific peer reviewers, the Services issued a final rule on November 17, 2000, effective December 18, 2000 (65 FR 69459). The final rule confirmed the endangered species listing as proposed, and amended it to incorporate "river-specific hatchery populations of Atlantic salmon having historical river-specific characteristics."

In the final rule listing the GOM DPS, the Services deferred the determination of inclusion of fish that inhabit the main stem and tributaries of the Penobscot River above the site of the former Bangor Dam (65 FR 69464). The deferred decision reflected the need for further analysis of scientific information, including a detailed genetic characterization of the Penobscot population. Furthermore, the Services were committed to reviewing data regarding the appropriateness of including the upper Kennebec and other rivers as part of the DPS (19 June 2003, letter from R. Bennett and P. Kurkul to Maine Governor Baldacci).

In late 2003, the Services assembled a new BRT comprised of biologists from the Maine Atlantic Salmon Commission (Joan Trial), the Penobscot Indian Nation (Clem Fay), NMFS (Tim Sheehan, Jessica Pruden, and Rory Saunders), and USFWS (Meredith Bartron, Anne Hecht, and Scott Craig). The new BRT was charged to review and evaluate all relevant scientific information necessary to evaluate the current DPS delineations and determine the conservation status of the populations that were deferred in 2000 and their relationship to the currently listed GOM DPS. This Status Review presents those findings.

Section 3: Biological Information

3.1 Life History

Atlantic salmon have a complex life history that ranges from territorial rearing in rivers to extensive feeding migrations on the high seas. As a result, Atlantic salmon go through several distinct phases in their life history that are identified by specific changes in

behavior, physiology, and habitat requirements (Figure 3.1). The following sections detail the life history typical of Atlantic salmon originating from U.S. rivers.

3.1.1 Freshwater Habitat

Watersheds with naturally reproducing Atlantic salmon populations vary widely in physical characteristics. However, for salmon to survive and reproduce, habitat must exist within a watershed for (1) spawning in late autumn; (2) feeding and sheltering during the growing period in the spring, summer, and autumn; and (3) overwintering. In addition, free migration among these habitats and the sea is necessary. Atlantic salmon habitat is best described using life stage specific combinations of depth, water velocity, substrate, and cover (Elson 1975, Egglishaw and Shackley 1985, Gibson 1993, Baum 1997; see below). Salmon streams can generally be characterized as having moderately low (0.2%) to moderately steep (1.4%) gradient. In addition to riverine habitats, lakes and ponds can also be important rearing habitat for juvenile Atlantic salmon (see Klemetsen et al. 2003 for a detailed review).

Most adult Atlantic salmon ascend the rivers of New England beginning in the spring, continuing into the fall with the peak occurring in June. Historically, the majority of the Atlantic salmon in Maine entered freshwater between May and mid July (Meister 1958, Baum 1997). Baum (1997) described variations to this pattern in run timing. In other parts of the world, differences in run timing have been shown to be heritable adaptations to local environmental conditions (Hansen and Jonsson 1991, Stewart et al. 2002). Salmon that return early in the spring spend nearly five months in the river before spawning, seeking cool water refugia (e.g., deep pools, springs, and mouths of smaller tributaries) during the summer months. Olfactory stimuli likely mediate homing to natal streams (Stasko et al. 1973).

Figure 3.1. Life Cycle of the Atlantic salmon (diagrams courtesy of Katrina Mueller).

When a Maine Atlantic salmon returns to its home river after two years at sea (called a two sea winter or 2SW fish) it is on average 75 cm long and weighs approximately 4.5 kg. Some salmon, typically males, return after only one year at sea (1SW fish) at a smaller size and are termed "grilse." For the period of 1967 to 2003, approximately 10% of the wild and naturally reared origin adults returning to U.S. rivers (with monitoring facilities) were grilse and 86% were 2SW (USASAC 2004). An occasional 3SW salmon is found among returning adults. In Maine, 95 to 98% of the grilse are male while 55 to 75% of the 2SW and 3SW returns are female (Baum 1997). These ranges are a result of annual variation. Once in freshwater, adult salmon stop feeding and darken in color. Spawning occurs in late October through November.

Atlantic salmon are iteroparous (i.e., capable of spawning more than once). The degree of iteroparity is not known with certainty, but approximately 20% of Maine Atlantic salmon return to the sea immediately after spawning while the majority overwinter in the river and return to the sea the following spring (Baum 1997). Post-spawn salmon in freshwater are called kelts or black salmon. Upon returning to estuarine and marine environments, kelts resume feeding and recover their silver color. If a rejuvenated kelt survives another one to two years at sea, it will return to its home river as a "repeat spawner." From 1967 to 2003, approximately 3% of the wild and naturally reared adult returns to monitored rivers in the U.S. were repeat spawners (USASAC 2004). Thus, a spawning run of salmon may include several age groups, ensuring some level of genetic exchange between generations.

Preferred spawning habitat is a gravel substrate with adequate water circulation to keep the buried eggs well oxygenated (Peterson 1978). Water depth at spawning sites is typically 30 cm to 61 cm and water velocity averages 60 cm per second (Beland 1984). Spawning sites are often located at the downstream end of riffles where water percolates through the gravel or where upwellings of groundwater occur (Danie et al. 1984). The optimal water temperature during the spawning period ranges from 7.2°C to 10.0°C (Jordan and Beland 1981, Peterson et al. 1977). The female uses its tail to scour or dig a series of nests in the gravel where the eggs are deposited; this series of nests is called a redd. One or more males fertilize the eggs as they are deposited in the redd (Jordan and Beland 1981). The female then continues digging upstream of the last deposition site, burying the fertilized eggs with clean gravel. Total size of completed redds in Maine average 2.4 meters (m) long and 1.4 m wide (Jordan and Beland 1981). A single female may create several redds before depositing all of her eggs. In Maine rivers, eggs on average are buried under 12 to 20 cm of gravel. Female anadromous Atlantic salmon produce a total of 1,500 to 1,800 eggs per kilogram of body weight yielding an average of 7,500 eggs per 2SW female (Baum and Meister 1971). Weight loss attributable to spawning in females ranges from 12% to 47% (Baum and Meister 1971).

The eggs hatch in late March or April. At this stage, they are referred to as alevin or sac fry. Alevins remain in the redd for about six more weeks and are nourished by their yolk sac (Gustafson-Greenwood and Moring 1991). Alevins emerge from the gravel in mid-May. At this time, they begin active feeding are termed fry. The majority of fry (>95%)

emerge from redds at night (Gustafson-Marjanen and Dowse 1983). Survival from the egg to fry stage in Maine is estimated to range from 15 to 35% (Jordan and Beland 1981, MacKenzie and Moring 1988). Stream gradient, overwinter temperatures, interstitial flow, predation, disease, and competition affect survival rates (Bley and Moring 1988). Within days, the fry enter the parr stage, indicated by vertical bars (parr marks) visible on their sides; parr marks act as camouflage (Jones 1959).

Parr prefer areas with adequate cover, water depths ranging from approximately 10 cm to 60 cm, water velocities between 30 and 92 cm per second, and water temperature near 16°C (Beland 1984, Beland et al. 2004). A territorial instinct, first apparent during the fry stage, grows more pronounced during the parr stage as the parr actively defend territories (Allen 1940, Kalleberg 1958, Mills 1964, Danie et al. 1984). Water temperature (Elliot 1991), parr density (Randall 1982), photoperiod (Lundqvist 1980), competition (Hearn 1987, Fausch 1998), and food supply all influence the growth rate of parr (Swansburg et al. 2002). Maine Atlantic salmon rivers can potentially produce from 5 to 10 large parr (age 1 or older) per unit of habitat; one habitat unit equals 100 square meters of suitable habitat (Elson 1975, Baum 1997). Juvenile Atlantic salmon feed on larvae of mayflies and stoneflies, chironomids, caddisflies, blackflies, aquatic annelids, and mollusks as well as numerous terrestrial invertebrates that fall into the river (Scott and Crossman 1973, Nislow et al. 1999). In fall as flows increase and temperature and day length decrease, parr often shelter in the substrate (Rimmer et al. 1983, Rimmer et al. 1984). Movement may be quite limited in the winter (Cunjak 1988, Heggenes 1990); however, movement in the winter does occur (Hiscock et al. 2002a, Hiscock et al. 2002b) and may be necessary as ice formation reduces total habitat availability (Whalen et al. 1999).

Some male parr become sexually mature and can successfully participate in spawning with sea-run adult females. These males are referred to as “precocious parr.” This alternative reproduction strategy has important implications for effective population size (Martinez et al. 2000, Jones and Hutchings 2002) and inter-generational gene flow (Fleming 1998).

In a parr’s second or third spring (age 1 or age 2 respectively), when it has grown to 12.5 to 15 cm in length, a series of physiological, morphological, and behavioral changes occur (Schaffer and Elson 1975). This process, called “smoltification,” prepares the parr for migration to the ocean and life in salt water. In Maine, the vast majority of wild/naturally reared parr remain in freshwater for two years (90% or more) with the balance remaining for either one or three years (USASAC 2005). During the smoltification process, parr markings fade and the body becomes streamlined and silvery with a pronounced fork in the tail. The biochemical and physiological changes that occur during smoltification prepare the fish for the dramatic change in osmoregulatory needs that come with the transition from a fresh to a salt water habitat (Ruggles 1980, Bley 1987, McCormick and Saunders 1987, USFWS 1989, McCormick et al. 1998). Naturally reared smolts in Maine range in size from 13 to 17 cm and most smolts enter the sea during May to begin their ocean migration (USASAC 2004). During this migration,

smolts must contend with changes in salinity, water temperature, pH, dissolved oxygen, pollution levels, and predator assemblages.

Survival rates for early life stages are quite variable. Overall, survival from egg to the smolt stage is estimated to range from 0.13 to 6.09% with a 90% confidence interval of 0.5 to 3.5% survival (Legault 2004). Survival for the first year of parr life is estimated to range from 12 to 58% while survival for the second year, up to smoltification, is estimated to range from 17 to 50% (Legault 2004).

3.1.2 Marine Habitat

The marine life history of Atlantic salmon of U.S. origin is not as well understood as the freshwater phase. A major obstacle to the study of Atlantic salmon in the marine environment has been the relatively low density of salmon over the extended geographic range in the ocean (Figure 3.1.2; Hislop and Shelton 1993). However, in the last 10 years there has been substantial progress in understanding the marine ecology and population dynamics of Atlantic salmon. Central to this progress has been the work of assessment committees such as the U.S. Atlantic Salmon Assessment Committee (USASAC), the International Council for the Exploration of the Sea (ICES) Working and Study Groups (the North American Salmon Study Group (ICES-NASSG) and the Working Group on North Atlantic Salmon (ICES-WGNAS).

Figure 3.1.2. Generalized marine migration routes of U.S. origin Atlantic salmon.

Much of our knowledge of U.S. Atlantic salmon at sea has been derived from marking and tagging studies of fish stocked in the Connecticut, Merrimack, and Penobscot Rivers. Over the history of the U.S. program, marking has progressed from aluminum tags in the 1870s (Moring 2002), to fin clipping (1942 to 1962), to Carlin tags (1962 to 1992), to coded-wire tags (1985 to 1994), to Visual Implant Elastomer tags from 2000 to the present (Meister 1984, NASCO 1993, USASAC 2004). From these investigations, scientists have gained a better understanding of the movement and exploitation of U.S. Atlantic salmon at sea (Meister 1984, NASCO 1993, Reddin and Friedland 1993). Additional studies that have directly sampled Atlantic salmon in the ocean have also provided important insights into the marine ecology of this species (Dutil and Coutu 1988, Reddin 1988, Ritter 1989, Reddin and Short 1991). While our understanding of Atlantic salmon in the ocean is still incomplete, these investigations have helped discern movements, exploitation, and population dynamics (Meister 1984, NASCO 1993, Reddin and Friedland 1993, Friedland et al. 1993).

Atlantic salmon of U.S. origin are highly migratory, undertaking long marine migrations from their natal rivers to the Northwest Atlantic Ocean, where they are distributed seasonally over much of the region (Reddin 1985). The marine phase starts with the completion of smoltification and migration through the estuary of the natal river. Smolt movement in the predominantly freshwater sections of the estuary is thought to be relatively passive, progressing seaward on ebb tides and neutral or upstream on flood tides (Fried et al. 1978, Thorpe et al. 1981, Lacroix and McCurdy 1996). As smolts enter the more saline portions of the estuary, their movements are more directed and they move rapidly seaward at speeds averaging two body lengths per second (LaBar et al. 1978, Lacroix and McCurdy 1996).

Upon completing the physiological transition to salt water, the postsmolts grow rapidly and have been documented to move in small schools and loose aggregations close to the surface (Dutil and Coutu 1988). The postsmolt stage is probably the least understood period during the life history of Atlantic salmon; recaptures of postsmolts are limited because Atlantic salmon fisheries target older, larger fish. Most of the U.S.-origin postsmolt tag recoveries have come from incidental catch in herring and mackerel weirs in the Bay of Fundy and South Shore of Nova Scotia during the month of July (Meister 1984). Tag recoveries from sea-bird colonies have indicated that U.S. postsmolts are also present off eastern Newfoundland by the month of August (Montevecchi et al. 1988, Reddin and Short 1991). Upon entry into the nearshore waters of Canada, the U.S. postsmolts become part of a mixture of stocks of Atlantic salmon from various North American rivers. Postsmolts in the northern Gulf of St. Lawrence stay nearshore for much of the first summer. Decreasing nearshore temperatures in autumn appear to trigger offshore movements of these fish (Dutil and Coutu 1988). Postsmolts also occur off the Grand Bank and further North in the Labrador Sea during the summer and autumn (Reddin 1985, Reddin and Short 1991, Reddin and Friedland 1993), where the North American stock complex intermixes with fish from Europe and Iceland. The U.S. stocks of Atlantic salmon thus become a small portion of a larger mixed-stock complex.

Upon entry to the marine environment, postsmolts feed opportunistically, primarily in the neuston (near the surface). Their diet includes amphipods, euphausiids, and fish (Hislop and Youngson 1984, Jutila and Toivonen 1985, Fraser 1987, Hislop and Shelton 1993). As postsmolts grow, fish become an increasingly dominant component of their diet.

Because they are small, Atlantic salmon postsmolts are preyed upon by a wide array of piscine, mammalian, and avian predators (Hvidsten and Mokkelgjerd 1987, Gunnerød et al. 1988, Hvidsten and Lund 1988, Montevecchi et al. 1988, Hislop and Shelton 1993, Beland et al. 2001, Montevecchi et al. 2002). Predation rates are difficult to estimate because of the wide spatial and temporal distribution of Atlantic salmon at low densities and the large number and variety of potential predators.

Information on the overwintering of postsmolts at sea is limited. Based upon analyses of scales, it appears that growth is minimal during this time (Friedland et al. 1993). The location of stocks during the winter is uncertain, but high spring catch rates of one-sea-winter (1SW) Atlantic salmon in the Labrador Sea caused Reddin and Friedland (1993) to hypothesize that postsmolts overwinter in the southern Labrador Sea. It is also likely that some component of the North American stock complex may overwinter in the Bay of Fundy (Reddin and Friedland 1993).

The 1SW and multi-sea-winter (MSW) Atlantic salmon are thought to behave similarly to the postsmolts, moving through the top three meters of the water column (Reddin 1985). Aggregations of Atlantic salmon may still occur after the first winter, but most evidence indicates that they travel individually (Reddin 1985). At this stage, Atlantic salmon primarily eat fish (piscivorous), feeding upon capelin (*Mallotus villosus*), herring (*Alosa* spp.), and sand lance (*Ammodytes* spp.; Hansen and Pethon 1985, Reddin 1985, Hislop and Shelton 1993). Their increasing size makes them decreasingly vulnerable to predation by smaller piscivores that feed upon postsmolts. Although most Atlantic salmon are caught near the surface, they may also make foraging forays into deeper water (Hislop and Shelton 1993, ICES 2005).

3.2 Stock Structure

Atlantic salmon, like many other salmonids, exhibit strong homing tendencies (Stabell 1984). This leads to the formation and maintenance of stocks (see Ricker 1972) in undisturbed areas (Utter 2004). This strong homing tendency likely enhances a given individual's chance of spawning with individuals having similar life history characteristics (Dittman and Quinn 1996), and may also enhance their progeny's ability to exploit a given set of resources (Gharrett and Smoker 1993). Local adaptations allow local populations to survive and reproduce at higher rates than exogenous populations (Ritter 1975, Reisenbichler 1988, Tallman and Healey 1994).

Another important trait of Atlantic salmon is straying (movement of individuals among populations). There are two types of straying: effective straying and ineffective straying. Effective straying occurs when an individual originating from outside a given area successfully spawns. Ineffective straying occurs when an individual from outside a given

area enters the area but does not successfully spawn. Straying is the mechanism by which new environments are colonized (Milner et al. 2000). Thus, straying allows the species to expand and explore the diverse array of niches available (Waples 1991a). In addition, straying can help maintain the genetic diversity and viability of small populations through genetic exchange and increased effective population size (Reisenbichler et al. 2003). The ability to use ephemeral resources, yet maintain population structure and local adaptations is a key feature of Atlantic salmon that has allowed them to radiate across the north Atlantic and fill a variety of niches (Klemetsen et al. 2003).

Successfully managing stocks requires appropriate stock delineation. Biologically-based stock delineations can be based on any number of factors including genetic, ecological, morphological, or environmental data (Utter et al. 1993). Alternatively, the North Atlantic Salmon Conservation Organization (NASCO) defines a stock as a management unit comprising one or more salmon populations as established by managers (Crozier et al. 2003). Given this definition, the appropriate spatial boundaries for defining a stock may be unclear until the management decision facing the regulators is considered. However, different groupings may be appropriate for different purposes. All available genetic, ecological, morphological, and environmental data should be assessed to evaluate the appropriateness of the stock delineation in light of the specific management issue being faced (Begg and Waldman 1999). For Atlantic salmon, these stock delineations can be formed at various spatial scales ranging from continents to sub-watersheds.

Discrete salmon stocks are maintained by natural selection of local adaptations and precise homing to the river of origin (Ricker 1972, Taylor 1991). This characteristic maintains the structure of the stock, regardless of the geographic scale of interest (Quinn 1993, Klemetsen et al. 2003). Numerous studies have demonstrated a major genetic divergence between the North American and European continents based on blood proteins, allozymes, mitrochondrial DNA, ribosomal RNA markers, minisatellites, and microsatellites (see Wennevik et al. 2004 for review). At this highest level of differentiation, the European component can be further defined by the eastern-Atlantic and Baltic components (Verspoor et al. 1999). Within North America, there is genetic structuring both between Canada and the U.S. (King et al. 2001) as well as within each country (McConnell et al.1997, King et al. 2001, Spidle et al. 2003). Even within individual rivers, multiple salmon stocks may exist (Saunders 1981).

Stock identification has been conducted at the individual river level and has been used as supporting evidence for the need for river-specific management policies. Evidence for these delineations has been supported by recent improvements in stock identification techniques related to microsatellite genetic analysis (King et al. 2001). These techniques have also helped identify the fine-scale population structure at the sub-drainage level (Beacham and Dempson 1998, Garant 2000, King et al. 2000, Spidle et al. 2001). These data highlight the fact that Atlantic salmon exhibit complex population structuring over the entire spatial scale of the species.

Atlantic salmon range throughout the northern Atlantic Ocean and present numerous challenges on varying spatial scales to managers. Stock delineations are based on both biotic and abiotic criteria relevant to the populations in question and the spatial scale of these delineations is often shaped by the management question at hand. As an example, managers of the West Greenland mixed-stock fishery must be concerned with populations across the North Atlantic, whereas managers developing river-specific management plans will define their stock unit as the population contained within the individual drainage. Therefore, it is essential to identify the spatial scale of the management questions being considered and to define its appropriate stock grouping.

The Services developed the Distinct Population Segment (DPS) Policy (61 FR 4722) for the purposes of listing, delisting, and reclassifying 'species' under the Endangered Species Act of 1973, as amended (16 U.S.C. 1531 *et. seq*.). This policy requires that the population(s) of interest be both discrete and significant to the taxon to which they belong in order to be considered a DPS. This policy provides the framework for this Status Review as the BRT considers issues related to stock structure of Atlantic salmon in the U.S. These issues are addressed primarily in Section 6 of this report.

3.3 Ecological Setting

The ecological setting in which Maine Atlantic salmon evolved is considerably different than what exists today. Ecological changes that have occurred over the last 200 years are ubiquitous and span a wide array of spatial and temporal scales. Many of these ecological changes continue to operate today, and new impacts (e.g., invasive species) are developing and being discovered on a regular basis.

Prior to European colonization, Maine Atlantic salmon rivers supported abundant populations of other native diadromous fish species, including alewives (*Alosa pseudoharengus*), blueback herring (*Alosa aestivalis*), American shad (*Alosa sapidissima*), sea lamprey (*Petromyzon marinus*), anadromous rainbow smelt (*Osmerus mordax*), Atlantic (*Acipenser oxyrinchus*) and shortnose sturgeon (*Acipenser brevirostrum*), striped bass (*Morone saxatilis*), tomcod (*Microgadus tomcod*), and American eel (*Anguilla rostrata*). In addition, several native resident species, including brook trout (*Salvelinus fontinalis*), slimy sculpin (*Cottus cognatus*), blacknose dace (*Rhinichthys atratulus*), fallfish (*Semotilus corporalis*), and creek chub (*Semotilus atromaculatus*) among others, were common in freshwater habitats occupied by Atlantic salmon. Salmon co-evolved over time with these and other aquatic organisms native to these rivers. This resulted in riverine ecosystems whose long-term community stability and productivity likely depended on sustaining individual species functions; inter-species relationships; and connections with riparian zones, lakes, ponds, wetlands, estuaries, and the ocean.

The scarcity of quantitative pre-colonization data on the biotic and abiotic setting of Maine's salmon rivers and the Gulf of Maine poses a challenge. In fact, until the mid-1800s, documentation of these effects and resultant changes in Maine's coastal river and Gulf of Maine environments was sporadic and fragmented at best. Nevertheless, it is

important to consider the pre-colonization conditions (as is possible with available information) as those are the conditions that shaped Atlantic salmon populations. Over time, the frequency and rate of anthropogenic alterations to those conditions may have outpaced the ability of salmon to adapt.

3.3.1 Atlantic Salmon as Prey

Historically, large populations of clupeids, such as shad, alewife, and blueback herring, used these river systems as migratory corridors, spawning grounds, and juvenile nursery habitat. These species likely provided a robust alternative forage resource (or prey buffer) for opportunistic native predators of salmon during a variety of events in the salmon's life history. While many of the following relationships still require further testing, they are each supported by optimal foraging theory (see Smith 1996), empirical observations, or parallel relationships observed or modeled with other species (see Taylor 1990).

First, pre-spawn adult alewives overlap in time and space with Atlantic salmon smolts. With similar body size, numbers that exceeded salmon smolt populations by several orders of magnitude (Smith 1898, Collette and Klein-MacPhee 2002), and a higher caloric content per individual (Schulze 1996), alewives were thus likely a substantial alternative prey resource (i.e., prey buffer) that protected salmon smolts from native predators such as cormorants, otters, ospreys, and bald eagles within sympatric migratory corridors (Mather 1998, USASAC 2004).

Second, adult shad likely provided a similar prey buffer toward potential predation on Atlantic salmon adults by otters and seals. Pre-spawn adult shad would enter these same rivers and begin their upstream spawning migration at approximately the same time as adult salmon. Historically, shad runs were considerably larger than salmon runs (Atkins and Foster 1869, Stevenson 1898). Thus, native predators of medium to large size fish in the estuarine and lower river zones could have preyed on these 1.5 to 2.5 kg size fish readily.

Third, juvenile shad and blueback herring may have represented a substantial prey buffer from potential predation on Atlantic salmon fry and parr by native opportunistic predators such as mergansers, herons, mink, and fallfish. Large populations of juvenile shad (and blueback herring, with similar life history and habitat preferences to shad) would have occupied main stem and larger tributary river reaches through much of the summer and early fall. Juvenile shad and herring would ultimately emigrate to the ocean, along with juvenile alewives from adjacent lacustrine habitats, in the late summer and fall. Recognizing that the range and migratory corridors of these juvenile clupeids would not be precisely sympatric with juvenile salmon habitat, there nonetheless would have been a substantial spatial overlap amongst the habitats and populations of these various juvenile fish stocks. Even in reaches where sympatric occupation by juvenile salmon and juvenile clupeids may have been low or absent, factors such as predator mobility and instinct-driven energetic efficiency (i.e., optimal foraging theory) need to be considered since the opportunity for prey switching would have been much greater than today. The

opportunity for prey switching may produce stable predator-prey systems with coexistence of both prey and predator populations (Krivan 1996).

3.3.2 Atlantic Salmon as Predators

Atlantic salmon are significant predators during most of their life stages. Salmon parr may opportunistically consume small fish to supplement their primary foraging base of macroinvertebrates. The historical abundance of other diadromous species probably represented significant supplemental foraging resources for juvenile salmon in sympatric habitats.

In addition, anadromous rainbow smelt are known to be a favored spring prey item of Atlantic salmon kelts (Cunjak et al. 1998). A 1995 radio tag study found that Miramichi River (New Brunswick, Canada) kelts showed a net upstream movement shortly after ice break-up (Komadina-Douthwright et al. 1997). This movement was concurrent with the onset of upstream migrations of rainbow smelt (Komadina-Douthwright et al. 1997). In addition, Moore et al. (1995) suggested that the general availability of forage fishes shortly after ice break-up in the Miramichi could be critical to the rejuvenation and ultimate survival of kelts as they prepared to return to sea. Kelts surviving to become repeat spawners are especially important due to higher fecundity and as a naturally selected legacy of virgin spawners (Baum 1997, NRC 2004). The historical availability of anadromous rainbow smelt as potential kelt forage in lower river zones may have been important in sustaining the viability this salmon life stage. Conversely, the broad declines in rainbow smelt populations may be partially responsible for the declining occurrence of repeat spawners in Maine's salmon rivers.

3.3.3 Nutrient Cycling

The dynamics and ecological significance of nutrient cycling by anadromous fish species assemblages has been well established amongst co-evolved Pacific salmon species in west coast ecosystems (e.g., Bilby et al. 1996, Gresh et al. 2000, Beechie et al. 2003, Stockner 2003). However, the scientific basis and biological significance (to Atlantic salmon or otherwise) of any parallel nutrient cycling role that co-evolved clupeids, sea lamprey, or Atlantic salmon themselves, might assume in east coast salmon rivers is less well studied or understood at this time (Garman and Macko 1998, MacAvoy et al. 2000, Nislow et al. 2004). The presently low abundance of the other diadromous species could only reduce the net benefits that Atlantic salmon may derive. However, this ecological function was likely very important in explaining the tremendous production potential of Maine's Atlantic salmon rivers.

Historically, the upstream migrations of large populations of adult clupeids, along with adult salmon themselves, provided a conduit for the import and deposition of biomass and nutrients of marine origin into freshwater environments. Mechanisms of direct deposition included discharge of urea, discharge of gametes on the spawning grounds, and deposition of post-spawn adult carcasses (Durbin et al. 1979). Migrations and other movements of mobile predators and scavengers of adult carcasses likely resulted in further distribution of imported nutrients throughout the freshwater ecosystem.

Conversely, juvenile outmigrants of these sea-run species represented a massive annual outflux of forage resources for Gulf of Maine predators, while also completing the cycle of importing base nutrients back to the ocean environment. These types of diffuse mutualism are only recently being recognized (Hay et al. 2004).

Sea lampreys also likely played a role in nutrient cycling. Lampreys prefer spawning habitat that is very similar (location and physical characteristics) to that used by spawning Atlantic salmon (Kircheis 2004). Adult lampreys spawn in late spring, range in weight from 1 to 2 kg, and experience 100% post-spawning mortality on spawning grounds (semelparous). This results in the deposition of marine-origin nutrients at about the same time that salmon fry would be emerging from redds and beginning to occupy adjacent juvenile production habitats. These nutrients would likely have enhanced the primary production capability of these habitats for weeks or even months after initial deposition, and would gradually be transferred throughout the trophic structure of the ecosystem, including those components most important to juvenile salmon (e.g., macroinvertebrate production).

3.3.4 Other Co-evolutionary Relationships

Sea lampreys likely provide an additional benefit to Atlantic salmon spawning activity in sympatric reaches. In constructing their nests, lamprey carry stones from other locations and deposit them centrally in a loose pile within riffle habitat and further utilize body scouring to clean silt off stones already at the site (Kircheis 2004). Ultimately, a pile of silt-free stones as deep as 25 cm and as long as a meter is formed (Leim and Scott 1966, Scott and Scott 1988), into which the lamprey deposit their gametes. The stones preferred by lampreys are generally in the same size range as those preferred by spawning Atlantic salmon. Thus, lamprey nests can be attractive spawning sites for Atlantic salmon (Kircheis 2004). In addition, the lamprey's silt-cleaning activities during nest construction can improve the "quality" of the surrounding environment with respect to potential diversity and abundance of macroinvertebrates, a primary food item of juvenile salmon.

Historically, Maine's native freshwater mussel community was more diverse and abundant than the present assemblage (Nedeau et al. 2000). Due to their planktivorous trophic status and filter-feeding behavior, freshwater mussels play an important role in maintaining high water quality and cycling nutrients of both freshwater and marine origin (Nedeau et al. 2000). In addition, a substantially higher historical abundance and diversity of mussels in Maine's salmon rivers would have represented another rich source of forage for native predators (e.g., otter). The decline of several mussel species is likely linked with declines of the diadromous fish community since several native diadromous fish (including Atlantic salmon) served as intermediate hosts for the larval stage (or glochidia) of several species of native freshwater mussels (Nedeau et al. 2000). As an example, the alewife floater (*Anodonta implicata*) persists in coastal systems where access to anadromous alewives has not been obstructed (e.g., Damariscotta Lake in mid-coast Maine). It is reasonable to assume that overall mussel populations and diversity in Maine's salmon rivers, and their associated ecological function and values, are but a fraction of what they were historically, especially in headwater areas.

3.3.5 Habitat Availability, Accessibility, and Metapopulation Structure

It has been widely theorized that population genetic structure of anadromous Pacific salmon species conform to a metapopulation paradigm (e.g., Adkison 1995, Policansky and Magnuson 1998, Smoker et al. 1998, Cooper and Mangel 1999, Rieman and Dunham 2000)—a set of locally adapted breeding populations connected by some exchange among individuals over short to moderate temporal scales. This network of local populations provides a balance between local adaptation and the evolutionary flexibility and stability that result from exchange of genetic material among local populations (NRC 1996, McElhany et al. 2000, Ford 2004). Furthermore, NRC (1996) concluded that "maintaining a metapopulation structure with good geographic distribution should be a top management priority to sustain salmon populations over the long term." NRC (2004) asserts that this concept applies to anadromous Atlantic salmon as well. Thus, a healthy and stable anadromous Atlantic salmon metapopulation (or DPS) likely requires the long-term availability and accessibility of the entire geographic range of freshwater habitats required by each sub-population to successfully complete the species' life cycle. In exploring how diminished access to freshwater habitats (compared to historical conditions) might impact long-term abundance and stability of a salmon metapopulation or DPS, at least two different spatial scales should be considered.

Within an individual small coastal river or within an individual tributary to a larger river, adult salmon need unobstructed migratory corridors to and from high quality spawning and incubation habitat. Spawning habitat should be fairly proximal and accessible to a sufficient quantity, quality, and diversity (overwintering, summer thermal refugia, etc.) of rearing habitat to support the resultant juveniles. Abiotic conditions and cycles (e.g., annual hydrological regime; annual, seasonal and daily temperature cycles; gross water chemistry; physical structure of the stream channel and floodplain) and any short- or long-term variability therein, should be intact and natural in character and range. Even if all of these needs and conditions are met, the persistence of the population is not guaranteed (Routledge and Irvine 1999). However, a stable, self-sustaining population of Atlantic salmon is likely to perpetuate in such a system, with average abundance reflective of the quantity of habitat type that is most often limiting.

Atlantic salmon require a connected complex of freshwater and marine habitats with seasonal abiotic regimes and are relatively intolerant to changes or deficiencies in these aspects. There is a definable "range" of suitable biotic and abiotic conditions in which salmon can successfully survive and propagate (see life history above). For example, salmon historically occupied, and currently occupy (albeit in very low numbers), both the Mattawamkeag River and Piscataquis River subdrainages of the Penobscot River basin. Each watershed provides the habitat conditions cited above. However, these two subdrainages are also different in a number of watershed-level aspects, including geomorphology, hydrological regime, and base water chemistry. Such variability in component-watershed biotic and abiotic factors likely serves at least two critical functions.

First, over a relatively short time frame (e.g., 1 to 3 years), some variability in watershed level factors could mitigate the long-term effect of abiotic extremes that might occur on

one or several, but not all, watersheds (at the metapopulation scale) over that period. For example, a 100-year flood event that occurs in one sub-region and scours away the salmon redds in that sub-region, may occur at a much lower severity (e.g., a 20-year event periodicity) in nearby sub-regions, or not at all.

In another example, varying natural buffering capacity between watersheds may play a role in year class performance and survival. Spring run off resulting from melting snow pack might cause a watershed with naturally low buffering capacity to exceed the tolerance of juvenile salmon due to acidification or aluminum toxicity, thereby resulting in a year-class failure. Conversely, a neighboring watershed with higher natural buffering capacity, might maintain pH or aluminum levels within the tolerance of juvenile salmon. In either case, the degree of impact to the overall metapopulation size and to the recovery period required to re-establish the disturbed populations are both likely to be less under a scenario where salmon have access to and consistently occupy most or all freshwater habitat present across sub-regions (see McElhany et al. 2000). Furthermore, the metapopulation concept suggests relatively rapid re-colonization of short-term extirpation events via low levels of mixing and straying from adjacent populations that fared better over the same time period.

Second, over a much longer time frame (e.g., evolutionary scale), variability in watershed level factors in a given sub-region may result in small but biologically significant variations in genotypic and phenotypic diversity across populations. Thus, longer term impacts resulting from more gradual or "trend-like" environmental changes may be mitigated by the availability of a "reservoir of adaptability" represented by these ecologically significant differences in genetic and phenotypic structure across populations.

In conclusion, metapopulation theory suggests that the observed variability among anadromous salmonids is a solution to the variable environment with which they must cope (Bisbal and McConnaha 1998). Life history plasticity is one feature that enables Atlantic salmon to use a wide array of resources in both freshwater and saltwater environments (Klemetsen et al. 2003). Variable life history traits are often heritable (Hansen and Jonsson 1991) and appear to be an important "bet-hedging" strategy that allows some segments of a population to persist through times of unfavorable environmental conditions (Ellner and Hairston 1994, Hilborn et al. 2003).
By diminishing the variability in a given population's (or DPS') life history and available habitats, the contemporary ecological setting in Maine's salmon rivers may have effectively limited the number of available coping mechanisms over both contemporary and evolutionary timescales.

Section 4: Historic Distribution and Abundance

The known historic natural range of Atlantic salmon in U.S. rivers was from the Housatonic River in the south to the St. Croix River in the north (Kendall 1935, Scott and Crossman 1973). In fact, anadromous Atlantic salmon were native to nearly every major river north of the Hudson River (Atkins 1874, Kendall 1935; Figure 4.1). Beland (1984)

reported that at least 34 Maine rivers held Atlantic salmon populations at one time. Other sources report the number to be 28 (Kendall 1935, MacCrimmon and Gots 1979).

By the early 1800s, the Atlantic salmon runs in New England had been severely depleted, greatly reducing the species' distribution in the southern half of its range. The earliest impacts were from fishing, water quality degradation, and barriers to migration caused by waste disposal and waterpower development associated with the Industrial Revolution. Restoration efforts were initiated in the mid-1800s, but had little success due to the presence of dams and the inefficiency of early fishways (Stolte 1981). Natural Atlantic salmon runs had disappeared from southern New England Rivers by 1865. There was a brief period in the late 19th Century when limited runs were reestablished in the Merrimack and Connecticut Rivers by artificial propagation, but these runs were extirpated by the end of the century (USFWS 1989). Salmon runs in the large rivers south of the Kennebec River, Maine, disappeared during this same period (Atkins 1874, Kendall 1935). By the end of the 19th Century, three of the five largest salmon populations in New England (in the Connecticut, Merrimack, and Androscoggin Rivers) had been eliminated, shifting the southern extent of the species' distribution approximately 2 degrees north in latitude and 4 degrees east in longitude.

The annual historic Atlantic salmon adult population returning to U.S. rivers has been estimated to be between 300,000 (Stolte 1981) and 500,000 (Beland 1984). The largest historical salmon runs in New England were likely in the Connecticut, Merrimack, Androscoggin, Kennebec, and Penobscot Rivers (DeRoche 1967, Baum 1983). Atkins and Foster (1867) estimated that the Penobscot alone held 100,000 adults annually. The Penobscot River continued to support a substantial wild population during the late 1800s, with a reported commercial catch of over 10,000 salmon in 1880 (Baum 1997). In subsequent years, a new artificial propagation program initiated in Maine influenced population abundance and distribution. However, the abundance of Atlantic salmon generally continued to decline in all remaining rivers with salmon populations through the last half of the 19th Century and first half of the 20th Century. By the mid-20th Century, the total adult run of Atlantic salmon to U.S. rivers had declined from hundreds of thousands of fish in the early part of the previous century to a probable range of 500 to 2,000 fish, mostly in rivers in eastern Maine (Baum and Jordan 1982, Beland et al. 1982, Fletcher et al. 1982, Fletcher and Meister 1982, Meister 1982, Baum 1983, Dube 1983). One of the best years for angling harvest during the period from 1948 through 1970 was in 1959 when a total recreational catch of 479 salmon was reported. Of these, 450 (94%) were caught in five rivers in Washington County (Baum 1997). The recreational catch reported for the Penobscot that year was only two fish. The primary distribution of Atlantic salmon in the U.S. by the mid-20th Century was, except for a few remnant populations, limited to the eastern third of Maine's coast.

Figure 4.1. Selected historic Atlantic salmon rivers in the Northeast U.S.

Section 5: Artificial Propagation

Large numbers of both anadromous (sea-run) and landlocked (non-anadromous) Atlantic salmon at all life stages have been transferred between watersheds and across governmental boundaries throughout North America. These transfers have had the potential to degrade the genetic integrity of local populations and thereby decrease the survival and fitness of locally adapted stocks (Brannon et al. 2004, Myers et al. 2004). A detailed examination of past and current hatchery practices is requisite to understanding the status of extant populations of Atlantic salmon in Maine.

Currently within the state of Maine, artificial propagation of Atlantic salmon can be grouped into five production categories: (1) production of landlocked Atlantic salmon for recreational fisheries by the Maine Department of Inland Fisheries and Wildlife (MDIFW); (2) private aquaculture production; (3) production and rearing for restoration or conservation of anadromous, captive-reared, or domestic broodstock; (4) research for both conservation and aquaculture; and (5) permanent feeding or rearing stations that use progeny of all broodstock for supplementation purposes directed by state and federal agencies.

5.1 Hatcheries and Feeding Stations in Maine

The first salmonid hatchery in Maine was constructed for culturing brook trout (*Salvelinus fontinalis*) in 1864 in the Sheepscot River drainage near the town of Alna (Locke 1969). In 1870, Atlantic salmon purchased from the Canadian government at Newcastle, Ontario were transferred to the Alna hatchery (Locke 1969). These fish were successfully raised and 1,500 fingerlings were stocked into the Sheepscot River in 1871 (Baum 1997). At roughly the same time, the first public salmon hatchery in the U.S. was constructed. This facility later became known as Craig Brook National Fish Hatchery (CBNFH). Charles Atkins, the first superintendent of the hatchery, pioneered several innovative fish culture techniques that are still used today (see Moring 2000 for a detailed review). Since the late 1800s, approximately 75 freshwater salmonid fish culture facilities (hatcheries that spawn and rear, and/or feeding-rearing stations) have operated within Maine. Appendix 1 lists the historical facilities described by Locke (1969). Most historic fish culture facilities were located in the southern region of Maine, primarily in the Presumpscot, Androscoggin, and Kennebec watersheds.

Today, 15 facilities are culturing Atlantic salmon in Maine (Appendix 2). Three facilities raise Atlantic salmon for aquaculture purposes. Four state hatcheries raise landlocked Atlantic salmon. Two federal hatcheries spawn and rear progeny of anadromous, captive reared, and domestic Atlantic salmon. Two facilities conduct research on stocks obtained from federal hatcheries. Four permanent feeding/rearing stations raise progeny of captive reared and domestic broodstock obtained from the federal hatcheries for recovery and restoration stocking.

In addition to Atlantic salmon reared at federal and private hatcheries, approximately 130 schools and businesses participate annually in the USFWS Salmon-in-Schools and Atlantic Salmon Federation Fish Friends programs. Through these programs, participants

receive approximately 200 (sea-run or domestic) eyed eggs and a suggested curriculum to help educate students and the public about Atlantic salmon. Participants generally release fry produced from the 200 eggs in May and June, stocking approximately 19,000 fry into designated segments of appropriate rivers as permitted by the Maine Atlantic Salmon Commission (MASC; USASAC 2004).

5.2 Stocking Strategies and Numbers Stocked

Anadromous Atlantic salmon have been stocked in at least 26 rivers in Maine from 1871 to 2003. Over 106 million fry and parr and over 18 million smolts have been stocked during this period. Excess adult anadromous, captive, and domestic broodstock have also been stocked into at least 12 rivers in Maine. Appendices 3 (fry and parr), 4 (smolts), and 5 (adults) contain the annual anadromous stocking summaries for all rivers that have been stocked with anadromous Atlantic salmon in Maine.

5.2.1 Juvenile Stocking

The anadromous Atlantic salmon stocking strategy in Maine between the 1870s and 1930s depended heavily on fry releases. The greatest numbers of fish were stocked between 1896 and 1936. Early fry stocking methods primarily used cluster stocking in limited areas of a river. After 60 years of predominantly fry releases with limited success, the strategy shifted to parr stocking, which continued through the 1950s. Due to poor results from the parr stocking program, a smolt stocking program was implemented in the mid 1960s (Moring et al. 1995).

The construction of Green Lake National Fish Hatchery (GLNFH) in 1974, augmented with later changes in rearing techniques, allowed for an annual smolt production capacity of 600,000 salmon at this facility. Higher proportions of age 1 smolts were produced by utilizing better juvenile fish diets and enhanced water temperatures. These changes were implemented to increase annual smolt production and ultimately adult returns (Moring et al. 1995). Since 1993, age 1 smolts have been exclusively stocked in the upper Penobscot watershed at values ranging from 454,000 to 580,000 annually. To meet smolt production goals, this program relies on the collection of at least 150 adults at the trap at Veazie Dam annually. These Penobscot River adults are spawned in captivity at CBNFH. Fertilized eggs are later transported to the GLNFH for hatching and rearing until they are stocked as age 1 smolts. The resulting smolts are then stocked in the Penobscot River.

A substantial shift in stocking strategies occurred again in the early 1990s, when fry stocking largely replaced smolt stocking in most rivers. In 1991, the current river-specific fry stocking program was initiated. The new program was based on recommendations of the Maine Atlantic Salmon Technical Advisory Committee (TAC). This new strategy was intended to help protect and maintain genetic integrity and river-specific population structure of Atlantic salmon in Maine by allowing fish to spend more time in the wild thus allowing natural selection to occur throughout most of an individual's life history (Moring et al. 1995). For the river-specific fry stocking programs, parr are obtained annually from each river, and are raised separately (segregated by river) to maturity. These captive-reared broodstock are spawned when

mature, and resulting progeny are stocked in the river where their parents were collected as parr. The current target for fry stocking densities in Maine is approximately 100 fry per rearing habitat unit. Stocking targets were derived from data presented by Orciari et al. (1994). Fry stocking at much higher densities (200 to 2,800 per unit) in Scottish streams yielded a negative linear relation for survival to the end of the first growing season (Egglishaw and Shackley 1980) Current fry stocking densities in the Narraguagus, Machias, East Machias, Pleasant, Dennys, and Sheepscot Rivers are somewhat lower than actual target density to provide buffer space around observed redds. Furthermore, production capacity at CBNFH is limited to 500,000 fry for each of the aforementioned rivers and 2,000,000 fry for the Penobscot River. Actual stocking densities in the Penobscot River are much lower than in other rivers because of the capacity limitations and the vast amount of rearing habitat compared to other rivers.

In addition to river specific fry stocking, four smolt stocking programs are currently operating out of the two Federal fish hatcheries in Maine. First, the Penobscot age 1 smolt program produces roughly 500,000 smolts annually (see above). Second, approximately 50,000 age 1 smolts have been stocked annually into the Dennys River since 2001. These smolts were reared at GLNFH from river-specific eggs obtained from CBNFH. Third, GLNFH currently produces and rears age 1 smolts (Penobscot sea-run origin) for the Merrimack River. Finally, CBNFH produces roughly 10,000 river-specific age 2 smolts and 2,500 age 1 smolts for the Pleasant River.

5.2.2 Adult Stocking and Transfers

Because Atlantic salmon are iteroparous, post-spawn anadromous broodstock are either retained at the facility (captive-reared or domestic broodstock), or they are released following spawning. For example, roughly 90% of Penobscot anadromous fish spawned at CBNFH are returned to the Penobscot River. The remaining 10% are usually sacrificed for required disease sampling. However, in some cases adults have been stocked into non-natal rivers (Baum 1997). Recent adult stocking efforts include surplus captive-reared broodstock from CBNFH. Since 1996, 50-250 fish per year have been returned to their river of origin except for the Pleasant River, where the first release of surplus adults occurred in 2004 (USASAC 2005).

5.2.3 Current Stocking Strategies

The river-specific fry stocking program is the primary strategy used in the East Machias, Machias, Narraguagus, and Sheepscot Rivers (Table 5.2.3). Fry stocking is also used in the Kennebec, Saco, and Union Rivers although these are not river-specific programs in that most fry are derived from Penobscot origin. Fry originating from the St. John River are stocked in the Aroostook River. A combination of river-specific fry and river-specific smolt stocking is used in the Dennys, Penobscot, and Pleasant Rivers. The St. Croix received smolts of Penobscot origin up until 2004. Currently, the St. Croix International Waterway Commission is attempting to develop a river specific stock.

Table 5.2.3. Number of juvenile Atlantic salmon stocked in Maine, 2004 (USASAC 2005).

River	Fry	Age 0 Parr	Age 1 Parr	Age 1 Smolt	Age 2 Smolt	Total
Androscoggin	2,000	0	0	0	0	2,000
Aroostook	169,000	0	0	0	0	169,000
Dennys	219,000	44,000	0	56,300	0	319,300
East Machias	319,000	0	0	0	0	319,000
Kennebec	52,000	0	0	0	0	52,000
Machias	379,000	3,100	0	0	0	382,100
Narraguagus	468,000	0	0	0	0	468,000
Penobscot	1,812,000	369,200	0	566,000	0	2,747,200
Pleasant	47,000	0	0	0	8,800	55,800
Saco	375,000	0	0	5,400	0	380,400
Sheepscot	298,000	15,600	0	0	0	313,600
St. Croix	0	2,800	0	4,100	0	6,900
Union	3,000	0	0	0	0	3,000

5.2.4 Broodstock Sources Through Time

The Penobscot River was the primary source of anadromous Atlantic salmon eggs for artificial propagation efforts in Maine between 1871 and 1919. Approximately 91 million eggs were taken from anadromous Penobscot salmon during this time period (NRC 2004). Of these eggs, roughly 41.2 million (38.5 million as fry, 0.3 million as age 0 parr, and 2.4 million as age 1 parr) were stocked back into the Penobscot. Most of the remainder of the eggs were transferred to New Hampshire, Massachusetts, Connecticut, Vermont, New York, Rhode Island, and Michigan according to various agreements of the New England Regional Fisheries Commission (Atkins 1882, Baum 1997).

In the early 20th Century, declining salmon runs and price disputes with commercial trap-netters reduced the amount of Penobscot-origin eggs available for artificial propagation. From 1920 to 1964, the vast majority of anadromous Atlantic salmon eggs propagated in Maine were obtained from the Canadian Maritime Provinces (Figure 5.2.4.1). The principle sources during this time were New Brunswick (primarily Miramichi River) and Quebec (Saguenay River; NRC 2004). During this period approximately 23.2 million eggs were purchased from New Brunswick and 2.3 million eggs were purchased from Quebec. The use of Canadian salmon eggs declined in the 1940s when the Machias and Penobscot River became primary sources of broodstock for coastal Maine hatcheries. During the 1950s and early 1960s, a lack of Penobscot River fish once again resulted in Canadian salmon being used as the primary source of eggs in Maine. In the early to mid-1960s, Machias and Narraguagus origin eggs largely replaced Canadian origin eggs. The use of Machias and Narraguagus origin eggs continued through the late 1960s and early 1970s. At this time, the restoration of the Penobscot salmon run was greatly enhanced through new stocking techniques, the construction of new and/or improved fish passage facilities, and improved water quality (Moring et al. 1995). By the early to mid-1970s, increasing adult returns to the Penobscot River resulted in a self sufficient propagation program and also completely supported the egg needs of the coastal hatcheries in Maine

(St. John River excluded). No eggs were purchased from Canada between 1965 and 1985 and the last two annual shipments to coastal Maine hatcheries occurred in 1986 and 1987 (NRC 2004).

The percentage of within basin (and consequently out-of-basin) fry and parr stocking varies widely across rivers (Figure 5.2.4.2, Appendix 6). The East Machias, Penobscot, and Machias Rivers had the most within basin stocking (88, 87, and 71% respectively). Out-of-basin stockings represent roughly 27% of all fry and parr stocking in Maine from 1871 to 2003. Sixteen rivers had greater than 90% of the total fry and parr stocked from out-of-basin sources; however, in these cases most of the donor stocks are other Maine rivers. For example, only 12% of all fry and parr stocked in the Pleasant River came from within basin sources but nearly the entire remainder came from other Maine rivers. Only nine percent of all fry/parr stocked in the Pleasant River come from sources outside Maine.

The percentage of within basin (and consequently out-of-basin) smolt stocking also varies widely across rivers (Figure 5.2.4.3, Appendix 7). The Penobscot and St. John Rivers had the most within basin smolt stockings (93 and 89% respectively). Ten rivers had over 90% of the total smolts stocked from out-of-basin sources. These out-of-basin stockings represent 22% of all smolt stocking in Maine during this period. Similar to fry/parr stocking, when smolts were stocked from out-of basin sources they were often from other Maine rivers. For example in the Dennys River, 41% of the total smolts stocked came from within basin sources, 43% came from other Maine rivers, and only 16% came from sources outside Maine. The within basin percentages for the Union River may be overestimated as many of the smolts stocked in the 1980s were ultimately of Penobscot origin.

Figure 5.2.4.1. Annual number of sea-run Atlantic salmon eggs obtained from the five largest donor stocks for Maine's fish culture facilities (1871 to 2003). Data from NRC (2004) and USASAC (1996 to 2004). Note: Captive reared river-specific broodstock from Narraguagus and Machias Rivers have been utilized since this program began in 1991.

Figure 5.2.4.2. Origin of Atlantic salmon fry and parr stocked in selected rivers from 1871 to 2003.

Figure 5.2.4.3. Origin of Atlantic salmon smolts stocked in selected rivers from 1871 to 2003.

Annual stocking efforts in the Penobscot River have occurred 118 of 130 possible years during the period from 1873 to 2003. The total percentage of within-basin stocking in the Penobscot River is higher than most other rivers in Maine. The total percentage of within basin fry/parr and smolt stocking in the Penobscot River up to year 2003 was 88% and 93% respectively while the percentage of within basin stockings for all other rivers in Maine was 44% and 23% for fry/parr and smolt stocking respectively. Prior to the river-specific rearing program (initiated in 1991), the most common donor (highest numbers) for Maine rivers was the Penobscot anadromous stock. Today, the Penobscot domestic broodstock program, maintained at the Green Lake National Fish Hatchery, serves as the donor stock for the Saco, Union, and Kennebec Rivers.

5.3 Landlocked Atlantic Salmon Stocking in Maine

Landlocked salmon are native to four watersheds in Maine: the St. Croix, including West Grand Lake in Washington County; the Union, including Green Lake in Hancock County; the Penobscot, including Sebec Lake in Piscataquis County; and the Presumpscot, including Sebago Lake in Cumberland County (Warner and Havey 1985). Beginning in 1868, landlocked salmon have been stocked extensively throughout the state in order to create or improve recreational fisheries. Over 51 million landlocked Atlantic salmon have been stocked into over 300 water bodies throughout Maine between 1937 and 1999 (Warner and Havey 1985; Steve Wilson, MDIFW, personal communication). Four state hatcheries in the towns of Embden, Casco, Enfield, and Grand Lake Stream currently raise landlocked salmon. Today, landlocked salmon provide primary fisheries in 176 lakes comprising nearly 500,000 acres in Maine. Continued hatchery stocking is required to maintain fisheries in 127 of these lakes. Landlocked salmon also provide fisheries in 44 rivers and streams totaling about 290 miles (MDIFW 2004). Genetic and ecological interactions between landlocked and anadromous Atlantic salmon are described in Section 6 and Section 8 of this Status Review.

5.4 Summary of Artificial Propagation

At least 75 historic fish culture facilities have produced Atlantic salmon in Maine. Although little data exists regarding these facilities (Locke 1969) as most were only operated for a few years. The majority of these historic facilities were located in Southwestern Maine with relatively few facilities being located east of the Kennebec River. Within the Penobscot River basin, approximately seven historic fish culture facilities were located above the head-of-tide near Bangor. Other than the federally operated Little Spring Brook facility that was in operation from 1904 to 1916 (Baum 1997), little information exists about other facilities (Locke 1969). Artificial propagation programs at CBNFH and GLNFH continue to produce Atlantic salmon today.

In some instances, Atlantic salmon populations, both within and outside Maine, have been completely extirpated then subsequently restocked with Penobscot, Narraguagus, or Machias origin fish. The BRT considers this a separate issue and is addressed in Section 6 of this Status Review.

Section 6: Consideration as a "Species" Under the ESA

6.1 Distinct Population Segment Analysis Background

6.1.1 Biological Background

Both anadromous Pacific salmon and Atlantic salmon exhibit important intraspecific sub-structure (Berst and Simon 1981). The intricate life history of anadromous salmonids together with their strong homing capability fosters the formation and maintenance of local breeding groups (i.e., stocks; Utter 2004). Stocks from a given area exhibit important, heritable adaptations to local riverine ecosystems (Hansen and Jonsson 1991, Nielsen 1998). The importance of maintaining local adaptations has been demonstrated in all three genera of anadromous salmonids in the northern hemisphere (Bisbal and McConnaha 1998, Klemetsen et al. 2003). Although accumulating evidence suggests that evolutionary coping may occur over contemporary time scales (e.g., Quinn et al. 2001), the widespread extinctions of local populations (Nehlsen et al. 1991, Parrish et al. 1998) suggest that present rates and forms of environmental changes may often exceed their capacities for adaptation (see Section 3 of this Status Review for a more detailed review).

6.1.2 Policy Background

Section 3 of the ESA (as amended in 1978) defines "species" to include "subspecies of fish, wildlife, or plants and any distinct population segment of any species of vertebrate fish or wildlife which interbreeds when mature." The 1995 Status Review for Anadromous Atlantic Salmon relied heavily on principles for defining Evolutionarily Significant Units (ESUs) of Pacific salmon (Waples 1991a, Waples 1991b) and adopted by NMFS (56 FR 58612) for defining "species" of Pacific salmon eligible for protection under the ESA.

In February 1996, the Services published a policy to clarify their interpretation of the phrase "distinct population segment" (DPS) for the purposes of listing, delisting, and reclassifying species under the ESA (61 FR 4722). The Services found that the DPS policy is consistent with the NMFS' ESU policy for Pacific salmon. While the ESU policy provides direction pertinent to its application to Pacific salmonids, the joint agency DPS policy added considerations related to international governmental boundaries. The DPS policy was addressed in the 1999 Atlantic Salmon Status Review and the 2000 listing under the ESA, and it provides the policy basis for re-examining the DPS delineation in this document.

The DPS policy requires the consideration of three elements when evaluating the status of a proposed DPS as endangered or threatened under the ESA: 1) the discreteness of the population segment in relation to the remainder of the species or subspecies to which it belongs; 2) the significance of the population segment to the species or subspecies to which it belongs; and 3) the conservation status of the population segment in relation to ESA listing standards. In this section of the Status Review, the BRT analysis focuses on the delineation of DPS structure for anadromous Atlantic salmon in the U.S. and

examines the first two elements−discreteness and significance. The vulnerability to extinction (i.e., conservation status) of Atlantic salmon DPS(s) will be considered in subsequent sections of this Status Review in relation to the listing factors and efforts underway to protect the species (sections 7 and 8).

In accordance with the DPS policy, a population segment of a vertebrate species may be considered discrete if it satisfies either one of the following conditions:

1. It is markedly separated from other populations of the same taxon as a consequence of physical, physiological, ecological, or behavioral factors. Quantitative measures of genetic or morphological discontinuity may provide evidence of this separation.

2. It is delimited by international governmental boundaries within which differences in control of exploitation, management of habitat, conservation status, or regulatory mechanisms exist that are significant in light of section 4(a)(1)(D) of the Act (i.e., inadequate regulatory mechanisms).

If a population segment is found to be discrete under one or more of the above conditions, its biological and ecological significance to the taxon to which it belongs is evaluated. This consideration may include, but is not limited to:

1. Persistence of the discrete population segment in an ecological setting unusual or unique for the taxon.

2. Evidence that the loss of the discrete population segment would result in a significant gap in the range of a taxon.

3. Evidence that the discrete population segment represents the only surviving natural occurrence of a taxon that may be more abundant elsewhere as an introduced population outside its historic range.

4. Evidence that the discrete population segment differs markedly from other populations of the species in its genetic characteristics.

While policy guidance relative to recognition of DPSs addressed in the1999 Status Review remains unchanged for the current review, considerable new scientific information has become available. In particular, new genetic information is now available to address important questions regarding the extent to which stocking efforts may have affected the genetic structure of remnant populations of Atlantic salmon in Maine. While stocking can be a valuable restoration tool, hatchery practices and stocking also carry risks that include inbreeding depression, outbreeding depression, and domestication. Thus, one of the challenges for previous BRTs and the Services has been to determine which Atlantic salmon qualify for and merit protection under the ESA, versus any fish that might be so severely intercrossed with exogenous stocks (or otherwise genetically compromised) that they could even constitute a threat to the

continued existence of the species in the wild. Faced with very limited genetic information, past BRTs have included in the DPS only salmon from areas where access to natal habitat was never interrupted for 12 or more years and that received minimal stocking of fish from outside its geographic range. As anticipated in the 2000 final rule and prior documents, this Status Review relies more heavily on genetic characterizations. In some cases, this may result in inclusion of populations in rivers that earlier Status Reviews excluded because of extended blockages to salmon access or stocking of exogenous salmon. Recent genetic information was also used to review delineation of the DPS boundary. The genetic information was considered together with new and old information regarding zoogeography, spatial arrangement of river systems, and salmon life history characteristics.

6.2 Analysis of DPS Structure Within the U.S.

Assessing DPS structure in wide ranging species such as Atlantic salmon requires broad scale consideration of geologic and climatic features that shape population structure through natural selection. For Atlantic salmon, factors such as climate, soil type, and hydrology are particularly important because these factors influence ecosystem structure and function including transfer of energy in aquatic food chains (Vannote et al.1980, Cushing et al. 1983, Minshall et al. 1983, Cummins et al. 1984, Minshall et al. 1985, Waters 1995). Since Atlantic salmon in the U.S. usually spend two years in rivers, a consideration of the broad scale factors that affect aquatic ecosystem function is necessary to understand how those factors would affect Atlantic salmon population structure in a given area. For example, Atlantic salmon at the extreme southern edge of their range may need to migrate earlier than those to the north in order to reach the ocean before the river warms beyond their temperature preference. Many ecological classification systems exist that integrate the many factors necessary to perform such an analysis.

Previous BRTs used classification systems devised by Bailey (1995 and 1998) and Maxwell et al. (1995). Bailey (1995 and 1998) used land forms, soils, vegetation, and topography to classify terrestrial ecosystems into ecological provinces. Similarly, Maxwell et al. (1995) used a variety of biophysical features to classify aquatic ecosystems. The 1999 BRT used these classification systems as well as the spatial arrangements of river systems that create isolation to delineate three DPSs in the U.S: Long Island Sound; Central New England; and Gulf of Maine. The 2005 BRT considers this delineation the “baseline” for DPS delineation in this Status Review. The following information was considered along with information found in the 1999 Status Review to re-examine DPS structure of anadromous Atlantic salmon in the U.S.

In 2003, Olivero (2003) published a new classification system specific to aquatic ecosystems. Olivero (2003) defined Ecological Drainage Units (EDUs) by aggregating watersheds with similar zoogeographic history, physiographic conditions, climatic characteristics, and basin geography. EDUs generally have similar physiographic and climatic conditions (Higgins et al. 2005). These features in turn influence fish and invertebrate community structure (Angermeier and Winston 1999). Thus, EDUs reflect

broad scale patterns of aquatic ecosystem function (Higgins et al. 2005). This system integrates much of the work done by Bailey (1995, 1998) and Maxwell et al. (1995) into one comprehensive ecological classification system for aquatic ecosystems. Previous classification systems (e.g., Bailey 1998) did not focus on aquatic systems. While Maxwell et al. (1995) did focus on aquatic ecosystems, even the sub-region delineations proposed are quite broad. For example, the Gulf of Maine sub-region extends from southern Massachusetts, U.S. to eastern Nova Scotia, Canada. In contrast, EDUs are often composed of a few moderate sized watersheds (e.g., Saco - Merrimack - Charles EDU). Alternatively, several EDUs may be encompassed by a particularly large watershed like the Connecticut basin. Given the strong homing tendencies of Atlantic salmon, the finer scale EDU approach is likely more informative in considering suites of environmental factors that would ultimately lead to the formation and maintenance of DPSs. For these reasons, the 2005 BRT relied more heavily on the EDU classification system than any other system in conducting a zoogeographic analysis of DPS structure for anadromous Atlantic salmon.

Within the historic range of Atlantic salmon in the United States, there are six EDUs: 1) the Lower Connecticut; 2) the Middle Connecticut; 3) the Upper Connecticut; 4) the Saco - Merrimack - Charles; 5) the Penobscot - Kennebec - Androscoggin; and 6) the Lower St. John - Lower St. Croix - and Downeast (Figure 6.2.1). The Middle Connecticut and Upper Connecticut EDUs are connected to the Atlantic Ocean by the Lower Connecticut EDU. The Lower Connecticut EDU drains into Long Island Sound while the EDUs to the north drain into the Gulf of Maine. In addition, the Cape Cod EDU is located between the Lower Connecticut and Saco - Merrimack - Charles EDUs; however, neither the 2005 BRT nor previous BRTs found any historical accounts of indigenous Atlantic salmon populations in the Cape Cod EDU.

The 2005 BRT also examined aquifer structure and groundwater temperature because groundwater can strongly influence stream temperature and consequently parr growth rates and egg incubation timing. Furthermore, since groundwater temperatures can be related to air temperatures (Meisner 1990), they reflect the range of climatic conditions over a given region. Groundwater temperature in the northeast is quite consistent and predictable ranging between 5°C and 10°C (also displayed in Figure 6.2a). Generally, groundwater temperatures in southern New England are slightly warmer than those in northern New England.

Unique to this Status Review, the 2005 BRT also examined nearshore marine community structure as part of its zoogeographic analysis. Given that nearshore areas are migration corridors for U.S. stocks of Atlantic salmon (Reddin 1988), they require consideration as each migration route likely has different predator assemblages and thermal regimes that influence life history events such as run timing. Offshore areas were not included as part of the zoogeographic analysis because most stocks in the Northwest Atlantic are thought to share similar overwintering and feeding areas in the open ocean (Reddin 1988). As with terrestrial and aquatic ecosystems, several classification systems for marine areas have been developed (Ketchum 1972, Terrell 1979, Cowardin et al. 1979, Ray et al. 1981, Alidina and Roff 2003). The 2005 BRT reviewed each of these classification

systems and did not find any one that was more informative than another for the present zoogeographic analysis. Each classification system does, however, describe a substantial break in physiographic conditions near Cape Cod. In short, marine communities to the north of Cape Cod are shaped by substantially different physical factors and thermal regimes than those to the south. Generally, nearshore areas north of Cape Cod are rockier and colder than those south of Cape Cod. For display purposes, the 2005 BRT used the classification system proposed by Ketchum (1972).

Finally, the 2005 BRT used biological information from extant stocks of Atlantic salmon to delineate DPS boundaries. A combination of life history characteristics and genetic information were used to support the delineation for the one remaining extant DPS (section 6.2.3).

The results from these analyses are detailed below, but in general the 2005 BRT concluded that the DPS delineations proposed by the 1999 BRT were largely appropriate. Therefore, the 2005 BRT believes that there are three DPSs of anadromous Atlantic salmon in the U.S.: Long Island Sound (LIS); Central New England (CNE); and Gulf of Maine (GOM; Figure 6.2b). Ideally, this determination would include genetic and other biological information from each DPS, but this was not possible because the extirpation of most native stocks in southern New England occurred in the 19th or early 20th Centuries. Furthermore, it should be noted that rivers in the LIS and CNE DPSs have been stocked with Atlantic salmon from the GOM DPS (see section 6.4). A description of each DPS and the various selection factors that lead to their delineation follows.

Figure 6.2a. Ecological drainage units (Olivero 2003), groundwater temperature (Meisner 1990), and coastal zones of the Northeast U.S (Ketchum 1972).

Figure 6.2b. Freshwater range of the Long Island Sound, Central New England, and Gulf of Maine Distinct Population Segments of Atlantic salmon.

6.2.1 Long Island Sound

The Long Island Sound (LIS) DPS includes all rivers from the Housatonic in Connecticut, northward to the Blackstone River in Rhode Island. The LIS DPS includes the Lower, Middle, and Upper Connecticut EDUs. Each of the small rivers in the LIS DPS lies entirely within the Lower Connecticut EDU while the Connecticut River itself extends into the Middle and Upper Connecticut EDUs. Rivers in the Lower Connecticut EDU are generally acidic, low gradient, low elevation systems (Olivero 2003). Tributaries of the Connecticut in the Middle and Upper Connecticut EDUs are characterized by increasing gradient and elevation. Rivers in the LIS DPS are spatially isolated from the other Atlantic salmon rivers in New England by Cape Cod. More precisely, the different physiographic conditions south of Cape Cod shape many selective factors. For example, Long Island Sound is a relatively large (175 km long, and 30 km wide) and shallow (24 m average depth) estuary that migrating smolts and adults would have to pass through. The southerly latitude of Long Island Sound and its shallow nature provide substantially warmer nearshore waters than the Gulf of Maine. This thermal regime likely imposes different time windows that smolts and adults could successfully complete their migrations. In addition, ground water temperatures are also generally higher in the LIS DPS than in DPSs to the North (Meisner et al. 1988, Meisner 1990). Specifically, the smaller rivers in the LIS DPS lie to the south of the 10°C groundwater isotherm. Warmer groundwater influences ecological factors such as food availability, assimilation efficiency, and ultimately growth rates (Allan 1995). Historically, this likely resulted in proportionally younger smolts being produced in the LIS DPS than in DPSs to the north because smolt age is strongly linked to temperature (Forseth et al. 2001). These differences in both freshwater and nearshore temperature regimes likely resulted in local adaptations (e.g., run timing) that differed substantially from stocks to the north.

The Long Island Sound DPS was likely extirpated by the early 1800s, with the loss of Atlantic salmon stocks indigenous to the Connecticut River (Meyers 1994). Atlantic salmon that inhabit this area today are the result of a restoration program that began in the 1960s using several donor stocks, primarily the Penobscot River in Maine (Meyers 1994, CRASC 1998). The ongoing supplementation program in the Connecticut River relies heavily on domestic broodstock for egg production needs (USASAC 2004). This program has been self sufficient for meeting its egg production needs since 1996 (CRASC 1998). Further discussion of the Connecticut program is included in sections 6.3.1.3 and 6.4 of this Status Review.

From Buzzards Bay northward along the coast of Massachusetts to the mouth of the Merrimack River, neither the 2005 BRT nor previous BRTs found any historical accounts of indigenous Atlantic salmon populations. This is likely a result of the small sizes and warm temperatures common to the low elevation, low gradient streams in the Cape Cod EDU (Olivero 2003).

6.2.2 Central New England

The Central New England (CNE) DPS includes all rivers from the Merrimack River to the Royal River. The CNE DPS lies entirely within the Saco – Merrimack – Charles EDU. The physiographic setting of the CNE DPS (i.e., the Saco – Merrimack – Charles

EDU) is quite diverse ranging from high gradient, high elevation systems to low gradient, meandering, marshy, coastal systems (Olivero 2003). The physiographic setting of the CNE DPS is quite similar to that in the LIS DPS. Consequently, native fish communities in the CNE and LIS DPSs, particularly those in the Lower Connecticut EDU, are quite similar (Olivero 2003). The primary reason that the 2005 BRT separated the CNE and LIS DPSs is the geographic separation between DPSs. The Blackstone River in the LIS DPS is the nearest "salmon river" to the Merrimack which is the southernmost "salmon river" in the CNE DPS. Prior to the construction of the Cape Cod Canal in 1914, the shortest distance between the mouths of these two rivers was roughly 300 kilometers. This distance alone would substantially limit the amount of straying between the CNE and LIS DPSs. Furthermore, the two DPSs would presumably have evolved different run timings as a consequence of the varying marine conditions described above.

The CNE DPS was likely extirpated in the mid-1800s, as documented by the loss of Merrimack River stocks (Stolte 1981, Stolte 1994). Early restoration efforts in the late 1800s had some success. Today, Atlantic salmon from the Penobscot River in Maine are stocked annually in the Merrimack and Saco Rivers. Further discussion of this issue is included in Section 6.4 of this Status Review.

6.2.3 Gulf of Maine

The GOM DPS is comprised of all anadromous Atlantic salmon whose freshwater range occurs in the watersheds from the Androscoggin northward along the Maine coast to the Dennys, including all associated conservation hatchery populations used to supplement natural populations; currently, such populations are maintained at Green Lake and Craig Brook National Fish Hatcheries. Excluded are those fish raised in commercial hatcheries for aquaculture.

The BRT was able to use both physiographic information and biological information from extant stocks to delineate the boundaries of the GOM DPS. Biological information for this analysis included genetic and life history information that was not available for the extirpated DPSs to the south.

The BRT delimited the geographical southern limit of the Gulf of Maine DPS as the southern border of Penobscot - Kennebec - Androscoggin EDU (Olivero 2003). This designation largely coincides with the terminus of the Laurentian Mixed Forest Province (LMFP; Bailey 1995, Bailey 1998) that was used by the 1999 BRT to delineate the southern terminus of the GOM DPS. The substantial changes in physiographic conditions south of the Androscoggin drainage are reflected in the southern terminus of both the LMFP and the Penobscot - Kennebec - Androscoggin EDU occurring in that area. Basin geography, climate, groundwater temperatures, hydrography, and zoogeographic differences between the Penobscot - Kennebec - Androscoggin EDU and EDUs to the south likely had a strong effect upon Atlantic salmon ecology and production. These differences would influence the structure and function of aquatic ecosystems (Vannote et al.1980, Cushing et al. 1983, Minshall et al. 1983, Cummins et al. 1984, Minshall et al. 1985, Waters 1995) and create a different environment for the development of local adaptations than rivers to the south.

The BRT delimited the geographical northern limit of the Gulf of Maine DPS as the northern boundary of the Dennys watershed (including the Dennys River). This conclusion is supported by the observed life history similarities (Baum 1997) and genetic structure among populations within the range of the GOM DPS (Spidle et al. 2003), life history similarities and genetic structure among salmon stocks to the north (Verspoor et al. 2002), and differences in life history strategies and genetic structure between the GOM DPS and salmon stocks to the north (Spidle et al. 2003, Baum 1997). Recent genetic studies show substantial differences between the GOM DPS and salmon stocks to the north (see Section 6.3.1.3 for a detailed review). Substantial differences in life history of GOM DPS and salmon stocks to the north are also apparent (see Section 6.3.1.2 for a detailed review). The observed differences in life history strategies and genetic structure are the basis of the northern boundary delineation. The BRT recognizes that this delineation does not match with a terminus of an EDU; thus, this delineation does not rely exclusively on ecological classification systems.

The charge of the 2005 BRT was limited to the U.S. range of Atlantic salmon, extending only as far into Canada as necessary to explore the northern limit of any DPS that might overlap the international boundary. However, the BRT is aware of efforts by the Canadian government to conduct similar analyses for stocks to the north of the GOM DPS (Larry Marshall, Fisheries and Oceans Canada, 2004, personal communication).

6.2.4 Summary

The 2005 BRT determined that the DPS delineations proposed by the 1999 BRT were largely appropriate. Table 6.2.4 summarizes each DPS delineation. Finally, it is important to note two differences between the current analysis and that conducted by the 1999 BRT. First, the 1999 BRT excluded fish inhabiting the three large rivers (Penobscot above the site of the former Bangor Dam, Kennebec above the site of the former Edwards Dam, and the Androscoggin). The decision to not include the large rivers in the GOM DPS was based on the lack of a comprehensive genetic survey when the 1999 Status Review was being prepared. That information is now available and is being considered in detail in section 6.3.1.3. Second, the 1999 BRT used the second discreteness criterion of the DPS Policy (i.e., the “International Boundary clause”) to delineate the northern border of the GOM DPS. The current analysis instead uses the first discreteness criterion based upon genetic information.

Table 6.2.4. Summary of DPS delineations.

DPS	Borders	Basis of Determination	Native Stock Status
Long Island Sound	Housatonic River, Connecticut to Blackstone River, Rhode Island	Physical isolation from CNE DPS; different marine conditions from CNE and GOM DPSs	Extinct
Central New England	Merrimack River, Massachusetts to Royal River, Maine	Physical isolation from LIS DPS; different marine conditions from LIS DPS; zoogeographic differences in the GOM DPS	Extinct
Gulf of Maine	Androscoggin River, Maine to Dennys River, Maine	Zoogeographic differences in the CNE DPS; life history and genetic differences in stocks to the north	Extant; see following sections of this Status Review

6.3 Assessment of the Gulf of Maine DPS

6.3.1 Discreteness

According to the Services' DPS policy (61 FR 4722), a population segment may be considered discrete if it satisfies either of the following two conditions:

1) it is markedly separated from other populations of the same taxon as a consequence of physical, physiological, ecological or behavioral factors. Quantitative measures of genetic or morphological discontinuity may provide evidence of this separation; or
2) it is delimited by international governmental boundaries across which there is a significant difference in control of exploitation, management of habitat, or conservation status.

The BRT used ecological, behavioral, and genetic factors under the first discreteness criterion to examine the degree to which the GOM DPS is separate from other Atlantic salmon populations.

6.3.1.1 Homing and Straying

Reproductive isolation does not have to be absolute to allow evolutionarily important differences to accrue in different population units, only strong enough for these differences to develop and be maintained (Wright 1978, Waples 1991a, Utter 2004). Geographical distance, behavioral differences, and temporal segregation of spawners can maintain reproductive isolation. The occurrence of exogenous Atlantic salmon in a stream does not necessarily represent a breakdown of reproductive isolation unless these fish spawn successfully, their progeny survive to spawn, and their presence degrades the survival and fitness of native stocks (Utter 2001). In fact, some genetic exchange

between populations can help to maintain genetic fitness by countering genetic drift (Waples 1991a).

Several tagging and recovery experiments have been conducted in Maine Atlantic salmon rivers to examine the extent of straying. Baum and Spencer (1990) assessed the homing of 1.2 million Carlin tagged, hatchery reared Atlantic salmon stocked as smolts between 1966 and 1987 into five rivers in Maine. Ninety-eight percent of all tagged fish recovered (n = 3,755) returned to the river where they were stocked. Of the few fish that did stray, most returned to the neighboring rivers except in the case of the Penobscot where most strays returned to the Kennebec and Androscoggin Rivers. Baum and Spencer (1990) attributed this pattern to the chemical "odors" of the large industrialized rivers being similar. Strays from the smaller rivers (e.g., Narraguagus) were found in the Penobscot as well as neighboring smaller rivers. In addition, some fish recorded in one river as strays eventually returned to their natal stream, which indicates that weir and trap recaptures may overestimate the number of fish that actually spawn in non-natal rivers (Baum 1997). Other researchers have shown that the straying rate of wild fish is typically lower than that of hatchery fish (Stabell 1984, Piggins 1987, Jonsson et al. 1991). Available information indicates that U.S. Atlantic salmon stocks do not stray far from their natal stream and thus supports the hypothesis that most straying documented between these river systems is limited to neighboring rivers within the geographic range of the GOM DPS.

6.3.1.2 Life History Characteristics

Life history characteristics in anadromous salmonids can have either an environmental (Forseth et al. 2001) or a genetic basis (Garant et al. 2003). Smolt age and age at spawning are two life history characteristics of Atlantic salmon that the BRT considered important in explaining population structure both within and among DPSs.

Juvenile growth is shaped by a combination of heritability, parental life history, and habitat quality (Garant et al. 2003). Smolt age reflects growth rate (Klemetsen et al. 2003), with faster growing parr emigrating as smolt earlier than slower growing ones (Metcalfe et al. 1990). Smolt age is largely influenced by temperature (Symons 1979, Forseth et al. 2001) and can therefore be used to compare and contrast growing conditions across rivers (Metcalfe and Thorpe 1990). For the GOM DPS, smolt ages (Table 6.3.1.1) are quite similar across rivers. Within the range of the GOM DPS, naturally reared returning adults predominantly emigrated at river age two (88 to 100%) with the remainder emigrating at river age three. The dominance of river age two smolts is consistent with data obtained from recent smolt monitoring efforts on the Penobscot, Sheepscot, and Narraguagus Rivers (USASAC 2004). Historical data obtained from the upper Narraguagus River (1960 to 1966; Baum 1997) and from the Sheepscot River (1956 to 1959; Stickney 1959) further support this pattern. Smolt ages from naturally reared returning adults in the LIS and CNE DPSs were also dominated by river age two smolts with some emigrating at river age three, but a substantial proportion of river age one smolts were also present (Table 6.3.1.1).

Table 6.3.1.1. Contemporary smolt age distributions (%) based on returning naturally reared adults for the Gulf of Maine (Penobscot, Dennys, Sheepscot, and Narraguagus Rivers), Central New England (Merrimack River), and Long Island Sound (Connecticut River) DPSs.

River	**Age 1**	**Age 2**	**Age 3**	**Age 4**
Penobscot	0	88	12	<0.1
Dennys	0	96	4	0
Sheepscot	0	100	0	0
Narraguagus	0	96	4	0
Merrimack	3	87	10	<0.3
Connecticut	8	88	4	0

The major exception to the age 2 smolt emigration pattern in the GOM DPS is the Penobscot smolt stocking program. This program produces age 1smolts for stocking by rearing in fish in an elevated temperature regime (see Section 5 of this Status Review), and is therefore not reflective of the natural freshwater rearing environment. Roughly 80% of all adult returns to rivers in Maine are fish that were stocked as age 1 smolts (USASAC 2004). Although these fish emigrate at age 1, they most often return after spending two winters at sea (USASAC 2004) as is characteristic of naturally reared adults within the range of the GOM DPS (USASAC 2004).

Differences in life history among U.S. Atlantic salmon stocks and those of Canada were identified as early as 1874 (Atkins 1874). Specifically, adults returning to U.S. rivers have been composed of predominately 2SW salmon (> 80%) from at least the late 1800s to the present (Atkins 1874, Kendall 1935, USASAC 2004). Alternately, many Canadian stocks and several in Europe have a much higher grilse component with a concurrently lower 2SW component that is frequently below 50% (Hutchings and Jones 1998). In rivers in southwest New Brunswick, adjacent to the GOM DPS, returns are predominantly 1SW (Marshall et al. 1999, Marshall et al. 2000, Jones et al. 2004). River size and proximity to the ocean have also been related to grilse proportion in Norway, with large-scale regional patterns in sea age, possibly related to ocean migration routes evident (L'Abee-Lund et al. 2004). Sea age at first maturity is known to have a genetic component (Gjerde 1984, Ritter et al. 1986).

The predominance of 2SW fish also influences the timing of the spawning run because older fish typically enter rivers earlier than grilse (Stewart et al. 2002). Trends in run timing among contemporary populations are difficult to discern due to low abundance and the lack of collection facilities on all rivers. Analyses of the recreational catch in

some Maine rivers has indicated that the timing of spawning runs has changed little in the past 50 years (Baum 1997). However, Juanes et al. (2004) noted an approximate 0.5 days per year decrease in the date of peak migration on the Penobscot River from 1978 to 2001.

Bernier et al. (1995) suggested that the proportion of grilse in the returns of Penobscot-origin salmon in particular increased, from the 1960s through the early 1990s as a result of hatchery practices including stocking Canadian-origin salmon. They also noted that exploitation of 2SW salmon and changes in sea conditions could affect the proportion of grilse. Examining the proportions grilse by cohort, removes bias associated with cohort strength. The resulting trends are an increasing grilse proportion with year and run size from late 1960s through the 1980s. During the 1970s the West Greenland fishery intercepted fish that would have returned as 2SW adults (ICES 2005). Salmon that returned as grilse were essentially unaffected by these fisheries because grilse from the U.S. do not migrate to West Greenland (Baum 1997). Thus, grilse returns seem to have held constant over the time period when the fishery was removing a substantial proportion of 2SW returns, leading to the perceived increase in grilse proportion. Friedland and Haas (1996), evaluating ocean growth of Penobscot River returns during this time period, noted that cohorts with good summer post-smolt growth had an increased proportion of 1SW returns. The proportion of grilse was stable (range 0.25 to 0.29) from 1985 to 1989. As returns declined in the 1990s, the proportion of grilse continued to increase, with more variability between years than the previous two decades. Both these patterns occurred as West Greenland fisheries interceptions of North American salmon were decreasing (ICES 2005) and correspond to a shift in 2SW Atlantic salmon survival in the North Atlantic (Chaput et al. 2005; see Section 8.5.3). If the increase in grilse rate were attributable to stocking of Canadian origin salmon, salmon in the Penobscot would be genetically similar to Canadian stocks; however, there is very little evidence of introgression from Canadian stocks (see Section 6.3.1.3).

The observed differences in life history characteristics seem to be a result of the GOM DPS' distinctness and remnant stocks have maintained these characteristics to the present day. Further, both environmental and genetic factors make the GOM DPS markedly different from other populations of Atlantic salmon in their life history and ecology.

6.3.1.3 Genetic Discreteness

Multiple studies have incorporated molecular markers to evaluate genetic relationships among Atlantic salmon populations. Markers used have included allozymes (Stahl 1987, Verspoor 2005, Cordes et al. 2005), mitochondrial DNA (Bermingham et al. 1991, King et al. 2000), and microsatellite markers (Morán et al. 1994, McConnell et al. 1997, Garant et al. 2000, Martinez et al. 2001, King et al. 2001, Spidle et al. 2001, Spidle et al. 2003, Spidle et al. 2004). The following review will focus on the most current information with the greatest range of populations analyzed.

<u>Continental Differences</u>

Atlantic salmon populations range from North America to Europe, across the northern Atlantic Ocean. Genetic differences between Atlantic salmon populations from North

America and Europe are significant enough that Atlantic salmon of unknown geographic origin can be correctly assigned to continent of origin with 100% accuracy (King et al. 2001). Differences in allele frequencies between European and North American Atlantic salmon populations have also been observed (Verspoor et al. 2005 and references therein). Therefore, the Atlantic salmon found in North America represent a genetically distinct group of populations.

North America

Genetic relationships among anadromous Atlantic salmon populations in North America were described in Spidle et al. (2003), Verspoor (2005), Cordes et al. (2005), and Verspoor et al. (2005). The analyses and interpretations in Spidle et al. (2003) incorporated results also presented in Spidle et al. (2001) and King et al. (2001) and represents the most current analysis of the largest set of samples for Atlantic salmon populations in both Maine and Canada (see Table 6.3.1.3.2 for full listing of populations examined and specific references). Cordes et al. (2005) used allozymes to analyze a subset of the Maine populations and one Canadian population examined in Spidle et al. (2003). Verspoor (2005) used allozymes to characterize a large number of Atlantic salmon populations in Canada. Verspoor et al. (2005) reviewed numerous allozyme-based studies to describe the genetic structure of Atlantic salmon populations throughout their range. Genetic analysis of the Connecticut River population and the genetic relationship between the Connecticut River to the Penobscot River populations was described in Spidle et al. (2004).

Table 6.3.1.3.2. List of populations genetically characterized, and the reference for the analysis with emphasis on populations in the United States. Additional Canadian populations have been analyzed, for example see Verspoor et al. (2005) for review.

River/Population	**Reference**
Canada	
Sand Hill River, Labrador	King et al. 2001, Spidle et al. 2003
Michaels River, Labrador	King et al. 2001, Spidle et al. 2003
Gander River, NF	Spidle et al. 2001, King et al. 2001, Spidle et al. 2003
Conne River, NF	King et al. 2001, Spidle et al. 2003
Saguenay River, Québec	King et al. 2001, Spidle et al. 2003
St. Jean River, Québec	King et al. 2001, Spidle et al. 2003
Miramichi River, NB	Spidle et al. 2001, King et al. 2001, Spidle et al. 2003
Gold River, NS	King et al. 2001, Spidle et al. 2003
Stewiacke River, NS	King et al. 2001, Spidle et al. 2003
St. John River (and tributaries), NB	King et al. 2001, Spidle et al. 2003, Cordes et al. 2005, Verspoor 2005
Dennis Stream (St. Croix estuary), NB	Spidle et al. 2003
United States	
Dennys River	King et al. 2001, Spidle et al. 2003, Cordes et al. 2005
East Machias River	Spidle et al. 2003
Machias River	Spidle et al. 2003, Cordes et al. 2005
Pleasant River	Spidle et al. 2003
Narraguagus River	King et al. 2001, Spidle et al. 2003, Cordes et al. 2005
Penobscot River	Spidle et al. 2001, King et al. 2001, Spidle et al. 2003, Cordes et al. 2005
Kenduskeag Stream	Spidle et al. 2001, Spidle et al. 2003
Cove Brook	Spidle et al. 2001, Spidle et al. 2003
Ducktrap River	Spidle et al. 2001, Spidle et al. 2003
Sheepscot River	Spidle et al. 2003
Kennebec River	Spidle et al. 2003
Togus Stream	King et al. 2001, Spidle et al. 2003
Bond Brook	Spidle et al. 2003
Connecticut River	Spidle et al. 2004
Sebago Lake (landlocks)	King et al. 2001, Spidle et al. 2003
West Grand Lake (landlocks)	King et al. 2001, Spidle et al. 2003

Genetic relationships among populations described in Spidle et al. (2003) were based on eleven microsatellite loci, and analyzed using multidimensional scaling, neighbor-joining phenograms of genetic distance (D_A; Nei et al. 1983), and assignment testing (Cornuet et al. 1999). Spidle et al. (2003) used multidimensional scaling analyses (MDS) of 1-D_A (Nei et al. 1983) to describe genetic similarity among populations. MDS indicated the most genetically similar Atlantic salmon populations in Maine were the Dennys, Narraguagus, Sheepscot, Penobscot, Pleasant, Machias, and East Machias populations

(Spidle et al. 2003). The next most closely related populations were the Ducktrap, Bond Brook, and Togus Stream populations (Spidle et al. 2003).

A second method used to examine relationships among populations was a neighbor-joining (NJ) phenogram depicting D_A (King et al. 2001, Spidle et al. 2003). NJ analyses are useful for describing genetic relationships among populations due to the statistical support for observed relationships through the use of bootstraps. Among Maine populations, observed genetic distances were small, and therefore the populations clustered together (Spidle et al. 2003). Within the Maine cluster, two groups were evident within the anadromous Maine populations (Spidle et al. 2003). Genetic differences between the two clusters were supported with bootstrap values of 70% or greater (Spidle et al. 2003). The first most closely related group consisted of the Pleasant, Narraguagus, Machias, East Machias, Togus, and Penobscot main stem population (Spidle et al. 2003). The Togus population clustered within the first group, but due to within-population differentiation, potentially a result of high mean relatedness (R=0.05; Spidle et al. 2003) was the most divergent population within the group. The second closely related group consisted of the Dennys, Bond Brook, Ducktrap, Sheepscot, and Kenduskeag populations (Spidle et al. 2003). The populations represented in the second Maine cluster were more genetically different compared to the populations in the first cluster. Within the second cluster, the populations from the Dennys and Bond Brook were most genetically similar, as were the Ducktrap and Sheepscot populations.

Assignment tests were used to examine the genetic distinctness of each population described in a geographically and biologically meaningful hierarchical structure (Spidle et al. 2003). The percentage of correct assignment of each population was described to river, DPS (Sheepscot, Ducktrap, Narraguagus, Pleasant, Machias, East Machias, Dennys, and Cove Brook), DPS (as defined in 2000) plus the Penobscot (Spidle et al. 2003), and nation. Individuals were assigned back to the baseline without replacement to determine the likelihood of each genotype being found in the baseline. In comparison to the neighbor-joining phenogram, the populations with the longest branch lengths also had the highest to-river assignment score (Spidle et al. 2003). Comparisons of the percentage correct assignment of Maine populations to DPS (as defined in 2000) and DPS/Penobscot main stem groups demonstrated an increase in percentage of correct assignments following inclusion of the Penobscot River population to the baseline (Spidle et al. 2003). The increased correct assignment of Maine populations to a group that includes the 2000 delineated DPS populations and the Penobscot supports the genetic similarity of Penobscot-origin individuals to populations in other rivers in Maine.

The population sampled from Cove Brook (a tributary to the Penobscot estuary) was the most genetically different population sampled by Spidle et al. (2003). The genetic distinctness of Cove Brook most likely was due to the large number of unique alleles (n=3.1) found within the population, high relatedness (R=0.03), and low number of estimated effective breeders (N_b=11; Spidle et al. 2003). As viewed by D_A, the node differentiating Cove Brook from other populations was represented by 90% or greater bootstrap support, and Cove Brook was grouped with populations from Canada (Spidle et al. 2003). The differentiation of Cove Brook from other populations in Maine was

attributed to the absence of stocking and sampling of potentially related individuals (Spidle et al. 2003). Given the historical use of Canadian-origin Atlantic salmon for stocking into the Penobscot (see Section 5), the genetic similarity of Cove Brook to the Canadian populations analyzed in Spidle et al. (2003) may reflect successful reproduction by some of those individuals within the Cove Brook population. However, neither the Penobscot main stem population nor the Kenduskeag population clustered similarly to the Canadian populations. Therefore, even if reproduction of Canadian stocks used for stocking in the main stem of the Penobscot was successful in Cove Brook (through straying), reproduction was limited to Cove Brook. Alternately, the genetic similarity of Cove Brook to the Canadian stocks could simply be a random event or an artifact of small population size and a genetic bottleneck event. Lage (2005) suggested that patterns of genetic diversity for the Cove Brook population (as well as Kenduskeag) are consistent with a genetic bottleneck event. Although the Kenduskeag does not cluster as tightly with other Maine populations in the MDS plot (Spidle et al. 2003), the neighbor-joining phenogram and assignment tests support the inclusion of the Kenduskeag with the other Maine populations (Spidle et al. 2003).

Recent restoration efforts of the Connecticut River Atlantic salmon population began in the late 1960s, with introductions of salmon from the Penobscot River and several Canadian rivers (Connecticut River Atlantic Salmon Commission (CRASC) 1998). Since 1976, only Atlantic salmon from the Penobscot River have been released into the Connecticut River (CRASC 1998). Genetic analysis (based on differences in allele frequencies) of individuals from the Connecticut River determined those individuals to be significantly genetically different from its primary (and most recent) source, the Penobscot River population (Spidle et al. 2004). Significant genetic differentiation between the two populations may be due to a variety of reasons. One potential explanation is the use of Canadian stocks in the Connecticut prior to 1976 (CRASC 1988). Even though adult returns from those stocking events were low (CRASC 1998), remnant individual salmon may have interbred with introduced individuals, or the current population represents an admixed result of spawning between remnant stocks, introduced Canadian stocks, and introduced Penobscot individuals. Alternate explanations include the effects of differential selection on the Connecticut River population compared to the Penobscot River population, the reproductive isolation (low to non-existent levels of straying of GOM individuals into the Connecticut River) of the Connecticut River from Gulf of Maine populations, bottleneck events, sampling effects, or the result of stocking effects (i.e., low effective population size, selection of individuals used to stock, hatchery practices).

Within Canada, Atlantic salmon populations are more genetically different from each other than populations within Maine (Spidle et al. 2003, King et al. 2001). Greater differentiation among Canadian populations may be due to greater levels of within population diversity; however, observed heterozygosity, number of alleles per locus, unique alleles, and similar measures were not provided for Canadian populations (Spidle et al. 2003). Another reason for greater population differences observed between Canadian populations sampled include the broader geographic range surveyed and

increased geographic distance between populations (hence leading to greater reproductive isolation).

Verspoor (2005) quantified genetic variation among 53 Canadian populations of Atlantic salmon using allozymes. Little to no within drainage heterogeneity was observed with the exception of the St. John (Verspoor 2005). The authors attribute genetic differences within the St. John to limited gene flow among tributary populations due to the strong homing behavior of Atlantic salmon. Based on the year genetic samples were taken (1984; Verspoor 2005), the authors ruled out strong influences of aquaculture strays contributing to population differentiation (Verspoor 2005). Geographically-based regional clustering of populations was observed, including genetic support for inner versus outer Bay of Fundy genetic groups. Inner Bay of Fundy populations included the Gaspereau and Stewiake, and the outer Bay of Fundy populations included the Hammond, Saint John, Tobique, and Magaguadavic (Verspoor 2005). The authors cited additional literature to provide additional support for inner versus outer Bay of Fundy differentiation, through mtDNA haplotype distributions, regional life history divergence (Verspoor et al. 2002).

Genetic differentiation between Maine and Canadian populations was observed in Spidle et al. (2003), Cordes et al. (2005), and Verspoor (2005). Spidle et al. (2003) analyzed Atlantic salmon populations from thoughout Canada, including two outer Bay of Fundy populations geographically proximate to Maine: Dennis Stream (a lower estuary tributary of the St. Croix) and Nashwaak River (an upper estuarine tributary of the St. John). Microsatellite analyses in Spidle et al. (2003) and King et al. (2001) observed that the Canadian populations were significantly genetically differentiated from Maine populations . Both populations were more genetically similar to other Canadian Atlantic salmon populations analyzed (Spidle et al. 2003). Verspoor (2005) identified the St. John, one of its esturine tributaries (Hammond River), an upriver tributary (Tobique River) and the Magaguadavic River (enters Passamoquody Bay) as part of the outer Bay of Fundy regional genetic group. Genetic heterogeneity within the St. John and its tributaries indicated high rates of natal homing and subsequent low levels of gene flow among populations (Verspoor 2005). Genetic differentiation between the St. John population and Maine populations was also observed in Cordes et al. (2005) and Verspoor (2005).

The St. Croix River is a boundary river between the United States (Maine) and Canada (New Brunswick) that historically supported a self sustaining Atlantic salmon population. The wild St. Croix population is considered extirpated and has been stocked extensively with Penobscot River origin stock (Baum 1997). Recent restoration efforts relied on Penobscot River origin smolts (Baum 1997) until the 1990s. After that time, adults returning to the St. Croix were collected for broodstock and their progeny were subsequently stocked as fall parr. Given the very recent history of attempts to create a river-specific broodstock, any Atlantic salmon currently inhabiting the St. Croix River system would most likely genetically resemble the contemporary Penobscot River population. There is little to no natural reproduction within the St. Croix main stem and most tributaries, and therefore the stocked fish do not represent a naturally reproducing

population; however, broodstock collection and subsequent stocking continues (DFO 2002, Sochasky and Spencer 2003). Dennis Stream, which enters the St. Croix estuary, contained a naturally reproducing population of Atlantic salmon into the 1990s. However, current information indicates that this population has become functionally extinct. Parr were sampled from this population in 1995 for genetic characterization when no stocking had occurred within the system (Spidle et al. 2003). Therefore samples obtained from Dennis Stream were hypothesized to represent a remnant population. Considering that Dennis Stream is the most geographically proximate population to the St. Croix, it most likely would genetically resemble the extirpated native St. Croix population.

Adult samples from the Nashwaak River (a tributary the St John River near Fredericton) in 1992 and 1993 were used to characterize the St. John River (Spidle et al. 2003) The Nashwaak River is within the geographic range of the populations identified as the Outer Bay of Fundy genetic group (Verspoor 2005). Although genetic heterogeneity was observed among the St. John populations (Verspoor 2005), when analysed with other Canadian populations, St. John populations were found to be genetically similar in relation to other populations, and represented a geographic genetic group (the outer Bay of Fundy genetic group; Verspoor 2005). In the example of the St. Croix, the use of a tributary population to infer the genetic relatedness of extirpated or mainstem populations represent the best science available regarding the genetic status of these populations.

The Dennis Stream population is more genetically similar to the Nashwaak River population even though the Dennis Stream is closer geographicly to the Dennys River (Spidle et al. 2003). Potential explanations for the pattern of genetic differentiation among these three populations include natural features (e.g., currents, chemicals, geology) that act to direct returning adults to their natal river, natural or directed movement (i.e., straying or stocking) of Atlantic salmon between the Nashwaak River and Dennis Stream, differences in management of the St. John and St. Croix rivers and the Dennys River due to management by different agencies and the international boundary, or straying and subsequent introgression of aquaculture origin individuals. Genetic similarity of the Dennis Stream and the Nashwaak River population, and support of the St. John population and other St. John tributaries (Verspoor et al. 2005) to the outer Bay of Fundy populations, act to dispute (at least for the samples included in the Spidle et al. 2003 analysis) strong introgressive effects with aquaculture strains unless those strains were based on St. John River stocks. Regardless of the cause, the genetic differences between salmon in Dennis Stream and the Dennys River indicate low rates of exchange between populations; therefore, the international boundary coincides with some barrier to genetic exchange.

The data presented in Spidle et al. (2003) are clear in defining the genetic relationship among U.S. and Canadian populations, and support for genetic differences is also provided in Cordes et al. (2005) and Verspoor et al (2005). The genetic boundary seems to be located within the St. Croix River estuary. However, it is difficult, and potentially impossible, to know exactly where the physical boundary occurs because there are no genetic (or other life history) data from any remnant St. Croix mainstem population or

from additional estuarine tributaries on the eastern or western portions of the St. Croix estuary. The best available science indicates that the St. Croix River groups with other Canadian rivers and should not be included in the GOM DPS. There are a number of cautions associated with this:

1) A lower estuarine tributary may not reflect the genetics of the population of the main river; this is the case with Cove Brook and Kenduskeag Stream on the Penobscot. Since the St. Croix population is extinct, Dennis Stream provided the best surrogate sample. However, the degree to which Dennis Stream actually reflects the historical structure of the St. Croix population is unknown.
2) The sample from Dennis Stream was based on a fairly small (n = 63) sample collected in one year (1995) from parr. A small sample size of parr taken in one year runs the risk of sampling a few families rather than a population (see below). There was no information on the details of the sampling.
3) A small population, such as was found in Dennis Stream, is subject to genetic drift. This is particularly true since the St. Croix population was extinct; therefore, genetic drift cold not be countered by straying from the St. Croix.
4) The St. Croix is a very large river that is being typified genetically by a small stream located in its estuary. It is reasonable to theorize that the St. Croix may have contained more than one population, as was observed in genetically differentiated populations within the St. John River (Verspoor 2005).

Similarly, the use of genetic information from samples obtained from tributaries to the lower Kennebec River (Bond Brook and Togus Stream) as surrogates for the historical Kennebec River population represents the best available scientific information. While these populations may not be entirely representative of the historical genetic structure of the populations that inhabited the main stem of the Kennebec, their similarity to each other and to nearby populations supports the hypothesis that fish within the range of the GOM DPS are shaped by similar selective forces.

Another sampling issue important to note included the sampling of parr for the source of genetic material for several GOM DPS populations (Spidle et al. 2004, Spidle et al. 2003, Spidle et al. 2001, King et al. 2001). Potential implications for the use of juvenile salmonids in analyses of genetic population structure include biased results due to familial genetic differences because related individuals were sampled (Allendorf and Phelps 1981). To avoid such biases, samples from multiple years (if available) were pooled when parr or other juvenile life stages were sampled (Spidle et al. 2001, King et al. 2001, Spidle et al. 2003, Spidle et al. 2004). Spidle et al. (2003) justified pooling across year classes within rivers based on analysis of molecular variance because there was more variation across rivers than across year classes within rivers. To address the issue of sampling related individuals, Spidle et al. (2003) estimated relatedness for each population following Queller and Goodnight (1989).

In general, although the magnitude of genetic differences among Maine populations was smaller in comparison to genetic differentiation among Canadian populations, statistically significant genetic variation was found among all populations in Maine (Spidle et al.

2003, Cordes et al. 2005). The significant genetic differentiation among populations within the Gulf of Maine DPS (mean FST=0.02; Spidle et al. 2003) indicated little to no population interaction among contemporary populations, but potential genetic interaction through historic gene flow or a shared common ancestry among all the anadromous Maine populations surveyed. This finding supports the grouping of each anadromous population surveyed in Maine (excluding the St. Croix) into one DPS.

Several non-anadromous (or landlocked) populations were also recently examined to determine their genetic relationship to Maine's anadromous popualtions. In general, all landlocked salmon sampled in Maine were more genetically similar to each other based on neighbor joining phenograms of D_A, and together were genetically differentiated from the anadromous populations from both Maine and Canada (King et al. 2001, Spidle et al. 2003). Though not grouped directly with the anadromous populations in Maine, the landlocked populations were considered more genetically similar (perhaps due to shared ancestral origins) to the Maine populations than to the majority of the Canadian populations supported by bootstrap values for the NJ analyses (King et al. 2001, Spidle et al. 2003). Including the landlocked populations in the analyses weakened the bootstrap support for the anadromous Maine cluster.

Based on genetic analysis of population structure of Atlantic salmon populations in North America, three primary genetic groups of North American populations (Spidle et al. 2003, Spidle et al. 2004, Verspoor et al. 2005) are evident. These include the anadromous Gulf of Maine populations (those analyzed ranged from the Kennebec River to the Dennys River), non-anadromous Maine populations (supported through bootstrap analysis in Spidle et al. 2003), and Canadian populations (Dennis Stream and north, including substructure among Canadian populations described by Verspoor et al. 2005). The Connecticut River population is considered separated from Maine through geographic, geologic, and life history differences, although the Penobscot River was a recent source population. Any population not sampled within one of those geographic groups would most likely lie within the most proximate functional genetic group.

The relative degree of population differentiation within the three genetic groups varied greatly, with the Gulf of Maine anadromous populations more similar to each other than the Canadian populations are to each other. Based on analysis of genetic differentiation among all populations examined, populations sampled from within the Gulf of Maine are more similar to each other than to Canadian populations. Any population within the Gulf of Maine region not genetically characterized in Spidle et al. (2004), Spidle et al. (2003), Spidle et al. (2001), King et al. (2001), or Cordes et al. (2005) that could also likely genetically interact with these populations (either through directed stocking or indirect straying) also is likely to be genetically similar to the GOM functional genetic group. Therefore, recent research supports the inclusion of all anadromous Atlantic salmon whose freshwater range occurs in the watersheds from the Androscoggin northward along the Maine coast to the Dennys (see figure 6.2.2), including all associated conservation hatchery populations (including those currently maintained at Green Lake and Craig Brook National Fish Hatcheries) into one Gulf of Maine Distinct Population

Segment (GOM DPS; see, however, Section 6.4 for discussion of restoration programs outside the historic range of the GOM DPS).

The BRT considers this information sufficient to satisfy the DPS policy's requirement that a DPS be markedly separate from other populations.

6.3.1.4 Summary

The GOM DPS of Atlantic salmon is markedly separated from other populations of the same taxon (i.e., the GOM DPS is discrete). The zoogeographical basis of this separation within the U.S. is described in detail in Section 6.2. All native populations south of the GOM DPS have been extirpated. Stocks to the north of the GOM DPS have substantially different life histories and genetic structure. This separation is the consequence of strong fidelity to natal rivers and adaptations for local conditions. The mechanisms that drive and maintain this separation are well documented for all anadromous salmonids (Stahl 1981, Waples 1991a, Dodson et al. 1998, Utter 2004).

6.3.2 Biological and Ecological Significance

The second element of the Services' DPS policy is the consideration of the population segment's biological and ecological importance to the taxon to which it belongs. This consideration may include, but is not limited to, the following:

1) Persistence of the discrete population segment in an ecological setting unusual or unique for the taxon
2) Evidence that the loss of the discrete population segment would result in a significant gap in the range of a taxon
3) Evidence that the discrete population segment represents the only surviving natural occurrence of a taxon that may be more abundant elsewhere as an introduced population outside its historic range
4) Evidence that the discrete population segment differs markedly from other populations of the species in its genetic characteristics.

6.3.2.1 Persistence of the GOM DPS in an ecological setting unusual or unique for the taxon

Riverine habitat occupied by the GOM DPS is unique because these waters are near the southern extent of the current North American range of Atlantic salmon (Saunders 1981, Baum 1997). This habitat is also distinctive because its core lies within a unique ecological setting, the Penobscot - Kennebec - Androscoggin EDU (i.e., the Laurentian Mixed Forest Province) (Bailey 1995, Bailey 1998, Olivero 2003). The importance of this setting is evidenced by the production capability of its juvenile nursery habitat that allows production of proportionately younger smolts than Canadian rivers (Myers 1986, Baum 1997, Hutchings and Jones 1998). Further, three of the five largest historical Atlantic salmon runs in the U.S. occurred within the GOM DPS' Androscoggin, Kennebec, and Penobscot Rivers. Within the historic U.S. Atlantic salmon range, only the Connecticut River contained more habitat than the Kennebec and the Penobscot. By

occupying the southern-most freshwater habitat, Gulf of Maine Atlantic salmon must undertake the longest oceanic migrations of the species in North America. Occupation of the southern portion of the range exposes the GOM DPS to riverine and oceanic selection factors different from those experienced by more northern stocks. The BRT has concluded that the GOM DPS does persist in an ecological setting which is unique for the taxon.

6.3.2.2 Evidence that the loss of the GOM DPS would result in a significant gap or constriction in the range of the taxon

The GOM DPS represents the southernmost Atlantic salmon populations in the western Atlantic. The populations within the GOM DPS are the last remaining U.S. Atlantic salmon populations and their extinction would represent a significant range reduction. The importance of the GOM DPS to Atlantic salmon is magnified by the prior extirpation of population segments to its south, including very large populations in the Merrimack and Connecticut Rivers. Salmon from the GOM DPS are now serving as the "best available" source stock for restoration efforts in these rivers, where native stocks were completely extirpated. Further, the low rates of restoration stock returns to the Connecticut and Merrimack Rivers illustrate the value of conserving native stocks and the difficulties of repatriation if they are lost. The 2005 BRT has concluded that the extirpation of the GOM DPS would significantly constrict the range of the taxon.

6.3.2.3 Evidence that the GOM DPS differs markedly from other populations of the species in its genetic characteristics

Marked differences in genetic characteristics of the GOM DPS from other Atlantic salmon, discussed extensively in section 6.3.1 of this report, provide evidence of its biological significance, as well as its discreteness. The BRT does note that, while stocks adapted to southerly environments also exist in Europe, these salmon are highly divergent from their North American counterparts (King et al. 2001).

Finally, the BRT notes that low returns exogenous smolts (Canadian-origin; see Section 5) and differential survival to adult of GOM DPS smolts stocked outside the GOM DPS geographic range (see below) is tantamount to experimental evidence that the GOM DPS is locally adapted, and further evidence of its biological significance. Penobscot River hatchery smolts have been stocked in the Connecticut, Merrimack, Saco, and St. Croix rivers. From 1985 to 1994, returns to the Penobscot River averaged 33.9 adults per 10,000 Penobscot smolts; returns to the St. Croix averaged 17 adults per 10,000 Penobscot smolts; returns to the Merrimack averaged 5.5 adults per 10,000 Penobscot smolts; and returns to the Saco averaged 22.5 adults per 10,000 Penobscot smolts (USASAC data). Ritter (1975) also noted that tag returns for smolts from three Gulf of St. Lawrence stocks stocked into 11 New Brunswick and Nova Scotia rivers declined with distance from the source river. Jessop (1976) found higher returns for native smolts stocked in the Big Salmon River compared to a Gulf of St. Lawrence (Miramichi) and an outer Bay of Fundy (St. John) stock. Ritter (1975) believed that genetics likely played a role in the differential survival. Clark (1981) found stock specific orientation mechanisms

for smolts from two stocks, one from the Gulf of St. Lawrence and the other from the Outer Bay of Fundy while tracking both in Passamaquoddy Bay. Together, these lines of evidence suggest that the genetic differences observed (see Section 6.3.1) are not only substantial on their own, but also evidence of local adaptation to the Gulf of Maine specifically.

6.3.2.4 Summary

The loss of GOM DPS would be a significant loss to the Atlantic salmon taxon as a whole. The size of historic salmon runs, its present occupation of the southernmost freshwater habitat in North America, and distinctive life history and genetic characteristics all lead the BRT to conclude that the loss of the GOM DPS would be a significant loss to the Atlantic salmon taxon as a whole.

6.3.3 The Penobscot Population

The decision regarding the status of the Penobscot River population above the site of the former Bangor Dam was deferred in the 1999 Status Review due to a lack of genetic data. Since the listing decision in 2000 (65 FR 69459), additional research has become available which describes the partitioning of genetic variation, both within the Penobscot, and between the Penobscot and other rivers in Maine. Due to limited upstream fish passage facilities in the 1940s and 1950s, there is debate about the persistence of Atlantic salmon populations in the Penobscot River during that time period. The genetic data suggests that the contemporary spawning population in the Penobscot River is genetically differentiated from the other populations in Maine; however, the Penobscot River population is more genetically similar to other populations in Maine compared to other North American populations analyzed (Spidle et al. 2003). The 2005 BRT considered a number of hypotheses that would explain the genetic relationships among the GOM DPS populations given the status of the Penobscot River. Following are two hypotheses which are most plausible at this time.

1) The Penobscot River population was substantially reduced, but never completely extirpated. Although passage at main stem dams was substantially reduced, there were periods when passage was possible (Pratt 1946) and lower river tributaries (e.g., Kenduskeag and Ducktrap Rivers) may have served as refugia during times when main stem passage to upper river spawning areas was not possible. Trap catches and rod catches of the era suggest that some level of persistence did occur (Pratt 1946, Everhart et al. 1955, Cutting 1959, Everhart and Cutting 1967); however, it is impossible to know how many salmon actually returned to the Penobscot during this time period because a trap was only operated for one year from 1948 to 1968 (Baum 1997). Efforts to rebuild the stock in the 1960s and early 1970s included hatchery stocking from within basin sources; hatchery stocking from out-of-basin sources, primarily individuals from the Narraguagus and Machias Rivers; or straying adults from neighboring populations. This either resulted in the maintenance of the distinct "Penobscot" genetic characteristics, or in a new unique mixture of genetic characteristics from each of the potential source populations.

2) The Penobscot River population became functionally extinct, then was rebuilt completely through stocking of out-of-basin sources, primarily the Narraguagus and Machias Rivers. Cumulative passage inefficiencies at several main stem dams prevented biologically effective access to upriver spawning grounds and thus any adults returning to the rivers during the 1940s, 1950s, and 1960s were the result of ongoing stocking programs. The literature of the era indeed suggests that passage was severely compromised at most flows, and nearly impossible at some flows (Pratt 1946, Everhart et al. 1955, Cutting 1959, Everhart and Cutting 1967). When populations rebounded in the 1970s, the primary donor stocks were parr and smolts from the Narragugus and Machias (see Section 5). By the mid-1970s, returns to the Penobscot (ultimately of Narraguagus and Machias origin) rebounded enough to begin collecting broodstock from the Penobscot again. A combination of small population size, founder effects, and introgression between these two genetically unique stocks resulted in the creation of a new, genetically unique stock that can be genetically differentiated from both the Machias and Narraguagus populations.

There is not enough information to conclusively falsify either hypothesis; therefore, both remain plausible explanations of why the Penobscot stock clusters closely with the rest of the GOM DPS. Regardless of which (if either) of the two aforementioned explanations are correct, there is sufficient information to conclude that the GOM DPS (including the Penobscot) is both discrete and significant under the provisions of the DPS Policy outlined above. If the first hypothesis is correct, then the contemporary Penobscot population reflects the genetic character of its historical population and would clearly merit protection. Alternatively, if the second hypothesis is correct, then the contemporary Penobscot population reflects the genetic character of historical populations in the Narraguagus and Machias Rivers. Conserving the contemporary Penobscot stock in this case would still be biologically significant to the rest of the GOM DPS and indeed the Atlantic salmon taxon as a whole because (1) they represent the most robust effective donor stock having come from the a nearby geographic region (i.e., within the range of the GOM DPS), (2) they are the only stock that successfully returned as evidenced by the apparent lack of introgression from Canadian stocks, and (3) they maintain important life history characteristics (primarily age 2 smolts and primarily 2SW adults) known to be characteristic of salmon within the range of the GOM DPS from historical accounts.

6.3.4 Hatchery Populations

The BRT concluded that all conservation hatchery populations (including those currently maintained at Green Lake and Craig Brook National Fish Hatcheries) should be included in the GOM DPS. This decision was made using the framework put forward in NMFS' Hatchery Policy for Pacific Salmonids (70 FR 37204). Although that policy only applies to Pacific salmonids, the BRT concluded it was a reasonable standard to use for Atlantic salmon as well.

A key tenet of the Hatchery Policy is that "Hatchery stocks with a level of genetic divergence relative to the local natural population(s) that is no more than what occurs within the ESU." Additional considerations for inclusion of hatchery stocks into the ESU

as defined by the Hatchery Policy for Pacific Salmonids (70 FR 37204) include "the degree to which natural broodstock has been regularly incorporated into the hatchery population…the attention given to genetic considerations in selecting and mating broodstocks", which both may contribute to whether or not the hatchery population genetically differentiates from the natural population(s) used for establishment.

For the purposes of the GOM DPS, the level of divergence is minimal because: (1) the river-specific hatchery programs collect wild parr or sea-run adults annually (when possible) for inclusion into the broodstock programs (Bartron et al. 2006); (2) broodstocks are used to stock fry and other life stages into the river of origin and in some instances hatchery-origin individuals represent the primary origin of Atlantic salmon due to low adult returns (3) the lack of introgression from exogenous wild populations (Spidle et al. 2003); and (4) the lack of introgression from aquaculture fish because of screening (Bartron et al. 2006). Since the level of divergence is minimal, the Hatchery Policy suggests that hatchery populations should be considered part of the ESU (in this case, DPS).

However, the BRT notes the cautions of many authors, notably Hey et al. (2005) who provide a thorough review and caution the use of hatchery dependent populations in such decisions. Even within one generation, hatchery and wild fish can differ physiologically, developmentally, and genetically as a response to dissimilar environments (Hey et al. 2005; see also section 8.5.1 for discussion of risks of artificial propagation). Due to the importance of the conservation hatcheries in maintaining Atlantic salmon in Maine, management actions within the hatcheries are currently being implemented to minimize risks associated with hatchery programs and captive propagation (Bartron et al. 2006).

In other parts of the world, hatchery supplementation has been used to assist in restoring depleted Atlantic salmon populations (e.g., Milner et al. 2004). Ó Maoiléidigh et al. (2003) note that even with hatchery supplementation, successful rebuilding of salmon stocks becomes increasingly difficult when abundance levels are below critical levels, however.

6.4 Ramifications for Restoration Programs Outside the Historic Range of the GOM DPS

Atlantic salmon restoration efforts using hatchery-produced stocks of Penobscot River origin have been on-going for many years in several rivers outside the historic range of the GOM DPS, including the Connecticut, Merrimack, Saco, and St. Croix Rivers. Atlantic salmon were extirpated from the Connecticut River in the early 1800s and recent restoration efforts were initiated in 1967. Salmon of Canadian origin were used for stocking in the Connecticut from 1967 to 1975, and stocking efforts after 1975 used broodstock of Penobscot River origin. From 1978 through 1995, sea-run returns to the Connecticut River were spawned with broodstock of Penobscot origin. After 1996, supplementation with Penobscot broodstock was discontinued. Presently, the Connecticut restoration program largely relies on sea-run broodstock, domestic broodstock, and kelts (CRASC 1998, USASAC 2004). Over time, it is expected that

selective pressures in the freshwater environment as well as portions of the marine migration unique to the Connecticut River will produce a locally-adapted stock. Parallel efforts to develop a Merrimack River restoration stock continue, but supplementation with Penobscot River broodstock is still on-going (USASAC 2004). Very low returns of sea-run salmon to the St. Croix River have limited progress towards development of a river-specific restoration stock and reliance on Penobscot-origin broodstock is still very high. Current stocking in the Saco River utilizes the same stock produced for the Penobscot River (USASAC 2004).

The premise of the efforts, described above, for developing river-specific stocks for salmon rivers outside the historic range of the GOM DPS is that selective environmental pressures exerted over many generations will result in creation of a stock that diverges from the original restoration broodstock. Indeed, comparison of genetic characteristics in the recently founded Connecticut River population with that of its primary donor, the Penobscot, indicated that micro-satellite allele frequencies have already begun to diverge (Spidle et al. 2004). Over time, the repeated process of breeding sea-run returns should develop a stock that is increasingly adapted to its habitat.

Notwithstanding U.S. Fish and Wildlife Service guidance for planning and coordinating recovery (USFWS 1990) that discourages introduction of listed species outside their historic range, the BRT recognizes that these restoration efforts have been on-going for many years. Penobscot-origin salmon may well represent the best available stock for rivers in extirpated DPSs south of the Gulf of Maine. Over time, it is expected that the restoration process will result in a stock that reflects the selective pressures exerted by the local environment.

Section 7: Current Distribution and Abundance

7.1 Adult Abundance

Adult returns of Atlantic salmon within the range of the GOM DPS remain low relative to conservation escapement goals (USASAC 2005). Returns were highest in the Penobscot River, which has a large amount of available habitat and large-scale stocking program that includes smolt, parr, fry, and restocking of captured sea-run adults after spawning at CBNFH. Returns to smaller rivers where fry were stocked or that had some natural spawning in previous years also had very low documented returns. Adult returns to rivers and streams that were not stocked and did not have spawning escapement in previous years were extremely low (often less than 10).

Adult returns are estimated using either trapping facilities at a fishway or through redd counts. For 2004, adult salmon were counted at fishway trapping facilities on the Penobscot, Androscoggin, Narraguagus, and Union rivers and at semi-permanent weirs on the Dennys and Pleasant rivers (Table 7.7.1). In the Penobscot River, a total of 1,323 sea-run salmon were captured during 2004. Seven hundred and fourteen salmon were released back to the Penobscot River; the remainder was taken to CBNFH as broodstock. Thirty-five salmon were recaptured once after dropping downstream over the dam and

ascending the fishway for a second time with four fish recaptured twice and two of these fish being recaptured a third time. The total catch in 2004 represents an increase of 211 fish from the 2003 total catch of 1,112 sea-run salmon. Maine Department of Marine Resources (MDMR) passed a total of 11 salmon upstream at the fishway trap on the Androscoggin River. The majority of these fish were of hatchery origin and because there are no smolts or parr stocked in the system these fish were likely strays from the Penobscot. None of these fish were marked or tagged. On the Union River two salmon were captured at the Ellsworth Dam fish lift during 2004. Based on scale growth patterns, one fish was a stocked as a smolt and the other was wild. All adult returns to the Dennys, Narraguagus, and Pleasant were naturally reared.

Table 7.1.1. Adult Atlantic salmon returns counted in traps and weirs from 1997 to 2004; includes wild and hatchery origin fish.

Drainage	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**
Androscoggin	1	4	5	3	5	2	3	11
Dennys	0	1		2	17	2	9	1
Narraguagus	37	22	32	23	32	8	21	11
Penobscot	1355	1210	968	534	785	780	1112	1323
Pleasant	1			3	11	0	2	1
Union	8	13	9	2	0	5	1	1
TOTAL	1402	1250	1014	567	850	797	1148	1348

Redd counts were conducted on a several rivers and streams where trapping facilities do not exist (Table 7.1.2). Of particular interest are the three redds found in the St. George river. Two redds were located above Sennebec Pond and one below. This indicates that Atlantic salmon are now spawning above the site where Sennebec Dam once stood.

Table 7.1.2. Redd counts in Maine rivers from 1997 to 2004. Most river main stems could not be surveyed for redds in 2003 because of high water.

River	1997	1998	1999	2000	2001	2002	2003	2004
Cove Brook	4	5	0	1	0	0	0	0
Dennys	35	32	23	60	72	0	1	51*
Ducktrap	2	9	29	2	0	0	2	9
East Machias	11	74	24	10	5	5	1	10
Kenduskeag				2	0	0	3	0
Kennebec & Lower Tributaries					0	0	0	2
Machias	59	74	46	23	22	3	21	59+
Marsh					0	0	---	0
Narraguagus	78	58	44	21	24	6	17	23*
Passagassawaukeag					0	0	---	0
Pleasant	1	9	0	1	3	0	---	0
Sedgeunkedunk								0
Sheepscot	8	4	21	15	18+	4	2	8
Souadabscook	0	4	1	2	0	0	---	4
St. George								3

--- Counts were not made due to high water.
* Redd counts indicate more spawning fish than expected based on trap counts: on the Narraguagus fish passed over the ice control dam and were not trapped; on the Dennys these fish were, in part, pre-spawn river specific domestic broodstock.
+Pre-spawn river specific domestic broodstock were stocked in the Machias.

Estimated returns can be extrapolated from redd count data using a return-redd regression established from the 1991 to 2004 Narraguagus River and 2000 to 2004 Pleasant River assessments by the MASC (USASAC 2005). This analysis was used to estimate the 2004 returns to the Machias, East Machias, Pleasant and Ducktrap rivers, and Cove Brook. In 2004, pre-spawn captive broodstock were stocked in the Dennys and Machias Rivers. Redds associated with these stockings (less than 20 mature females in each river) were not used to estimate returns. The point estimate for returns to each of these rivers in 2004 was quite low, with the highest estimated returns (24) to the East Machias River (Table 7.1.3).

Table 7.1.3. Redd based estimates of adult returns in selected rivers in 2004.

River	Type	Estimate	90% CL Low	90% CL High
Cove Brook	redd	0	0	1
Dennys River	trap	1	1	1
Ducktrap River	redd	15	7	26
East Machias River	redd	24	10	49
Machias River	redd	16	8	28
Narraguagus River	trap	11	11	11
Pleasant River	trap	1	1	1
Sheepscot River	redd	14	7	25

Regardless of the method used to generate the estimate, reported returns generally underestimate the actual returns in a given watershed for a variety of reasons. First, a trap may not be 100% efficient. For example, adult salmon have been observed leaping over the ice control dam on the Narraguagus at high water. Since the trap for the Narraguagus is built into the ice control dam, not all adults are caught in that facility. Second, redd based estimates of abundance can be very difficult especially in high water years. Thus, reported adult returns can generally be considered minimum numbers not total numbers.

Conservation spawning escapement (CSE) goals, also called conservation limits, are widely used (e.g., ICES 2005) to describe the status of individual Atlantic salmon populations. CSE goals are set for accessible rivers using a method developed by Elson (1975). This method assumes a target egg deposition of 2.4 eggs/m^2 is needed to fully seed a river (Elson 1975); female fecundity averages 7,200 eggs/female (Baum and Meister 1971, Baum 1997); and a 1:1 male: female ratio exists (Baum 1997). For example:

With 100,000 m^2 of accessible habitat, target spawners would be:

100,000m^2 x 2.4 eggs/m^2 = 240,000 eggs;
240,000 eggs / 7,200 eggs/female = 33.333 females; and
33.333 x 2 = 66.67 = 67 Atlantic salmon

Once the escapement goal is calculated, a standardized comparison can be made among rivers of different size since adult returns are scaled as a percentage of the escapement goal. Simply put, CSE represents the percentage of the abundance index (trap count or extrapolated adult return from redd counts) divided by escapement goal. For example:

An escapement goal of 67 spawners and index of 35 spawners:
(35/67) x 100 = 52.23% of escapement goal

The estimated amount of accessible or available rearing habitat may vary from year to year, and thus, CSE also varies. Estimates of available habitat change as fishways are installed, dams are removed, and estimates of habitat in additional tributaries become available through surveys. An increase in the number of habitat units without a concomitant increase in returns would decrease the percentage of CSE goal attained. In recent years, most populations within the range of the GOM DPS are below 15% of their CSE goals (Table 7.1.4).

Table 7.1.4. Two sea winter (2SW) returns for 2004 in relation to spawner requirements for selected rivers within the geographic range of the GOM DPS.

River	Minimum Spawner Requirement (CSE)	2SW spawners in 2004	Percentage of Requirement (CSE)
Cove Brook	16	0	0.00
Dennys	161	1	0.62
Ducktrap	56	15	26.79
East Machias	200	16	8.00
Machias	463	24	5.18
Narraguagus	401	10	2.49
Penobscot	6,838	1,011	14.79
Pleasant	81	1	1.23
Sheepscot	186	14	7.53

7.2 Juvenile Abundance

Atlantic salmon juveniles are present in rivers where there has been recent spawning escapement or where fry, parr, or smolts have been stocked from CBNFH or GLNFH. During the period 1961 to 1978 on rivers where electrofishing surveys captured primarily natural reproduction, juvenile densities for many river systems had, on average, between 4 and 10 parr per habitat unit (MASC unpublished data). These surveys generally targeted areas thought to contain high parr densities. During the 1980s, Beland (1996) noted predictable relationships among redds and parr densities two years later on the Dennys River with parr densities as high as 14.1/unit. In recent years, sampling has been conducted in a wide variety of habitat types not just riffle habitat that was typically sampled in the 1960s and 1970s. The density of juveniles in stocked rivers in 2004 was comparable to that reported in the 1960s and 1970s.

7.2.1 Rivers Without Large Scale Stocking Programs

Some of the streams included in this group may have been stocked intermittently by school groups or for research projects. Stocking numbers per stream have been less than 1,000 fry (schools) and 1,000 parr (research on Kenduskeag Stream). Since 2000, surveys for juveniles have been conducted in tributaries to the Penobscot and Kennebec estuaries. Surveys for Atlantic salmon were discontinued on Tunk Stream after no juveniles were collected between 1994 and 1998. Captures of juveniles in Kenduskeag Stream, Felts Brook, and other small tributaries in upper Penobscot Bay since 2000 have not been consistent from year to year (Table 7.2.1). In 2002, 80 sites distributed throughout the Kenduskeag Stream drainage were electrofished; eight had juvenile salmon, with a total of 53 parr captured. When salmon, not directly attributable to stocking, have been present in these tributaries, densities have been less than 5 per unit for parr and 12 per unit for young-of-the-year (YOY). Juvenile Atlantic salmon have not been observed in Bond Brook or Togus Stream, tributaries to the Kennebec River estuary, since 2002, when one parr (possibly age 3) was captured during an electrofishing survey (Table 7.2.1.2).

Table 7.2.1.1. Presence (number of sites) of Atlantic salmon juveniles during electrofishing surveys on tributaries to the Penobscot River estuary.

Drainage	Year	YOY Absent	YOY Present	Parr Absent	Parr Present	Sites
Cove Brook	2000	3	0	0	3	3
	2001	2	0	2	0	2
	2002	3	0	3	0	3
	2003	3	0	3	0	3
	2004	5	0	5	0	5
Total		16	0	13	3	16
Ducktrap River	2000	0	5	5	0	5
	2001	3	0	0	3	3
	2002	3	0	0	3	3
	2003	4	0	3	1	4
	2004	2	10	12	0	12
Total		12	15	20	7	27
Kenduskeag Stream	2000	2	0	1	1	2
	2001	5	0	5	0	5
	2002	80	0	72	8	80
Parr stocked	2003	33	0	19	14	33
Parr stocked	2004	79	0	18	61	79
Total		199	0	115	84	199
Marsh Stream	2001	7	0	7	0	7
	2002	9	0	9	0	9
	2003	4	0	4	0	4
	2004	3	0	3	0	3
Total		23	0	23	0	23
Marsh Stream North	2001	12	0	12	0	12
	2002	11	0	11	0	11
	2003	3	0	3	0	3
	2004	2	0	2	0	2
Total		28	0	28	0	28
Marsh Stream South	2001	3	0	0	3	3
	2002	4	0	2	2	4
	2003	3	0	2	1	3
	2004	3	0	3	0	3
Total		13	0	7	6	13
Sedgeunkedunk Stream	2000	0	2	0	2	2
	2001	3	0	0	3	3
	2002	4	0	2	2	4
	2003	1	0	0	1	1
Total		8	2	2	8	10
Souadabscook Stream	2001	1	1	0	2	2
	2002	4	0	1	3	4
	2004	3	0	3	0	3
Total		8	1	4	5	9
Felts Brook	2002	1	0	1	0	1
	2004	1	0	0	1	1
Total		2	0	1	1	2
Grand Total		309	18	202	108	310

Table 7.2.1.2. Total catches of Juvenile Atlantic salmon in tributaries to the Kennebec River below the old Edwards Dam.

Year	Bond Brook			Togus Stream		
	YOY	Parr	Sites	YOY	Parr	Sites
2001	0	4	4	0	9	2
2002	0	0	3	0	1	2
2003	0	0	1	0	0	2
2004	0	0	1	0	0	2

7.2.2 Rivers With Large Scale Stocking Programs

Surveys to estimate density or relative abundance of juvenile salmon were conducted on most of the rivers in Maine with wild and stocked populations of Atlantic salmon (Table 7.2.2). On the Narraguagus River in 2004, parr densities varied among the sites sampled. In the main stem, densities ranged from zero to 7.91 parr/unit, and from zero to 21.64 parr/unit in tributaries. YOY densities were also variable in main stem sites (zero to 18.20/unit) and on the tributaries (1.18/unit to 24.37/unit). In 2004, six sites on the Sheepscot River contained no parr and the highest parr density was 10.05 parr/unit, with a median of 0.47 parr/unit for 27 sites. Parr densities in the Dennys River ranged from zero to 6.43 parr/unit in 2004, with a median of 1.8 parr/unit. Of these Dennys River parr, approximately 10% were stocked fall parr or residualized smolts. Parr densities at index sites monitored in the East Machias, Machias, and Pleasant Rivers ranged from zero to 23 parr/unit. Penobscot River electrofishing surveys were undertaken on three tributaries to the Mattawamkeag River (Big Gordon Brook, Little Gordon Brook, Mattakeunk Stream) and five tributaries of the main stem Penobscot River (Mattaceunk Stream, Pollard Brook, Hoyt Brook, Hemlock Stream, Salmon Stream). None of these tributaries are stocked, but they are tributaries to segments that are stocked or are accessible to adults. Juvenile salmon were found in Big Gordon Brook, Hemlock Stream, and at two sites on Mattakeunk Stream.

Table 7.2.2. Juvenile Atlantic salmon population densities (fish/100m^2) in 2004 on rivers with stocking programs or possible 2003 spawning escapement (Penobscot Tributaries are above Veazie Dam).

	Young-of-the -Year				Parr			
River	Minimum	Median	Maximum	Sites	Minimum	Median	Maximum	Sites
Dennys	0	3.88	17.25	25	0	1.8	6.43	25
East Machias	0	16.72	117.51	9	0	3.21	8.62	9
Narraguagus	0	7.44	24.37	39	0	3.21	21.64	39
Machias	1.6	15.34	45.58	11	0.75	3.25	12.11	11
Pleasant	0	20.81	45.94	3	0.49	5.53	22.7	3
Sheepscot	0	3.85	39.4	27	0	0.47	10.95	27
Penobscot Tributaries	0	2.76	20.9	8	0	1.5	2.05	8

7.2.3 Smolt Abundance

The NMFS and the MASC annually enumerate smolt populations using Rotary Screw Traps (RSTs) in several rivers in Maine (USASAC 2005). On rivers with parr and smolt stocking programs, hatchery origin smolts dominated catches. On the Penobscot River, a total of 1,614 smolts were captured during RST operations in 2004; 1.7% were naturally reared (wild origin or fry-stocked) and the remainder was hatchery-origin smolts. Of the smolts captured on the Pleasant River, 708 were hatchery smolts and 214 were naturally reared smolts. Of the 1,056 smolts captured in the RST on the Dennys River in 2004, 873 were hatchery smolts, 83 were naturally reared, and 100 were from fall parr stockings in 2002 or 2003. On the Sheepscot and Narraguagus Rivers where no parr or smolts were stocked, all smolts were naturally reared.

7.3 Conservation Status and Likelihood of Extinction

Statistical methods can quantitatively estimate population growth and extinction probabilities for a species. The size of a population and its corresponding growth rate are both important predictors of its extinction risk because a population exhibiting long-term continual decline will eventually go extinct. However, even if a population is not on average declining, there is still some probability that it will go extinct as a result of environmental variation or other stochastic processes. The probability of extinction is both a function of initial population size and productivity. However, it should be noted that long-term predictions about the productivity of any species is likely to be academic because the predictions generally assume that environmental factors remain unchanged. This leaves the reality of shorter term predictions being generally more reliable (Hanski 2002).

Population Viability Analysis (PVA) quantitatively estimates information related to population growth and extinction probabilities for a single population (Dennis et al. 1991). A simple PVA is a stochastic exponential growth model of population size that is equivalent to a stochastic Leslie-matrix projection within no density dependence. More complex PVA approaches have been developed whereby life history characteristics are accounted for within the model, such as the age distribution within the abundance measure.

The BRT decided to apply PVA techniques to assist in the determination of the conservation status of the GOM DPS. A software program produced by Paul McElhany (NMFS/NWFSC) and John Payne (University of Washington, Department of Zoology) was selected for this purpose. The program SPAZ (Salmon Population AnalyZer; version 1.0.0 alpha), available upon request from the authors, was used for modeling purposes.

SPAZ was designed to conduct PVA on salmonid populations. SPAZ projects current population growth trends and projects future population growth trajectories based on abundance, age structure, hatchery contribution, and catch data parameters. The projections produced by SPAZ can be used to evaluate extinction risk (i.e., proportion of trajectories falling below some minimum abundance level). SPAZ does not take into account the possibility of catastrophic events or any genetic effects that could influence

the interpretation of PVA results and the long-term sustainability of the model population.

Five main datasets were used to assemble the input file required by SPAZ: adult return and rod kill estimates (1969 to 2004) for the Penobscot River, adult spawners (1962 to 1974 and 1991 to 2004) and rod kill estimates (1962 to 2004) for the Narraguagus River and adult spawner estimates (1991 to 2004) for the GOM DPS (as previously defined in 2000). These data formed a basis for a composite dataset of adult spawners, catch and their corresponding age distribution representing the GOM DPS.

All PVA simulations were run under the "Running Sum Analysis" module. The Running Sum Analysis first estimates population growth rate and variance based on a weighted running sum of spawners, which considers age structure to approximate all current and future spawners within the system (i.e., multiple cohorts), and then projects into the future using these parameters to estimate extinction risk.

Two time series were chosen for evaluation (Figure 7.3) over the time period of 1980 to 2004. The BRT decided that this data set provided the best measure of the recent dynamics of these populations. Data from 1968 to 1979 were excluded from all analysis. The BRT believed that the adult spawner estimates from this time period were not representative of current populations. The dramatic increase in adult returns experienced on the Penobscot River during the 1970s, albeit well below estimated historic levels (Baum 1983), was likely due to changes in management (stocking) practices on the Penobscot coupled with favorable marine survival that resulted in increasing adult returns. Further, there was no comprehensive monitoring program prior to 1969.

The period from 1991 to 2004 was also evaluated because a "regime shift" has recently been described for Atlantic salmon populations in the North Atlantic (Chaput et al. 2005). This "regime shift" represents a change in productivity and marine survival of Atlantic salmon in the Northwest Atlantic that began in the early 1990s and has persisted to date. The recent assessment effort for the North Atlantic salmon complex estimated that the most appropriate year for assigning this shift was 1991 (ICES 2005). The time period of 1991 to 2004 was therefore evaluated to assist in determining the conservation status of the GOM DPS during this persistent current phase of low productivity.

Figure 7.3.1. Total adult returns (spawners and catch) for the GOM DPS (as previously defined in 2000) plus the Penobscot River; and the two time series evaluated for extinction risk, time series 1 runs from 1980 to 2004, time series 2 runs from 1991 to 2004.

There were two steps to the PVA undertaken. The first step was to estimate the population growth rate and variance and the second was to project into the future using these parameters to estimate extinction risk.

Lambda is the mean annual rate of increase (or decrease) in the population (>1=increase, <1=decrease, =1 flat). The variance around lambda is calculated from the time series of lambda. A summary of the GOM DPS growth as expressed by lambda and its associated variance is presented below:

Time series	Lambda	Variance
1980-2004	0.9690	0.0261
1991-2004	0.9471	0.0142

In both analyses, the trend was for negative population growth with the shorter time series characterized by a lower lambda. In addition, the variance estimate around lambda narrows as the time series becomes (1) more restrictive, (2) more consistent in trend, and (3) representative of the contemporary dynamics. Regardless of the results from the extinction risk estimation, lambda itself can provide some indication as to the status of the population under analysis. Low lambda values equal higher probability of extinction risk and require larger improvements in population growth (e.g., survival, fecundity) to avoid extinction. Small initial population sizes exacerbate this process, as there is a shorter time to extinction (Holmes 2001).

SPAZ uses the estimated population growth rate (lambda), its variance and the final running sum of the spawners to project into the future a user defined number of years for a user defined number of projections. Extinction risk is evaluated by recording the number of trajectories where the running sum of spawners falls below the user specified QET (quasi-extinction threshold). QET is a running sum value at which the population is considered to be extinct. A QET of one is generally considered functionally extinct. For the GOM DPS (as defined in Section 6 of this Status Review), substantial genetic and demographic problems would arise if total abundance were to fall below 100 adults. Specifically, the Penobscot smolt program requires 150 returning adults (see Section 5). If production goals could not be met, a continuing decline would be expected.

For both runs, QETs of 1, 50, and 100 were evaluated. The probability of falling below each QET value was evaluated at five time steps (0, 20, 40, 60, 80, and 100 years). The probability of extinction was based on the number of simulated trajectories that fell below the QET. For the 1980 to 2004 dataset, the estimated risk of becoming functionally extinct (running sum <1) in 100 years is 19% while the risk of falling below a QET of 100 is 5% in 20 years and 28% in 40 years (Table 7.3.2 and Figure 7.3.2).

Table 7.3.2. Estimated extinction risks based on the 1980 to 2004 dataset for the GOM DPS. Quasi-extinction thresholds of 1, 50, and 100 individuals were calculated at 20 year intervals.

	0 yrs	**20 yrs**	**40 yrs**	**60 yrs**	**80 yrs**	**100 yrs**
1 ind	0	0.000	0.008	0.046	0.110	0.189
50 inds	0	0.019	0.186	0.354	0.463	0.538
100 inds	0	0.053	0.281	0.446	0.546	0.605

Figure 7.3.2. Estimated extinction risks based on the 1980 to 2004 dataset for the GOM DPS. Quasi-extinction thresholds of 1, 50, and 100 individuals were calculated at 20 year intervals.

For the 1991 to 2004 dataset, the estimated risk of becoming functionally extinct (running sum <1) in 100 years is 37% while the risk of falling below a QET of 100 is 12% in 20 years and 45% in 40 years (Table 7.3.3 and Figure 7.3.3).

Table 7.3.3. Estimated extinction risks based on the 1991 to 2004 dataset for the GOM DPS. Quasi-extinction thresholds of 1, 50, and 100 individuals were calculated at 20 year intervals.

	0 yrs	**20 yrs**	**40 yrs**	**60 yrs**	**80 yrs**	**100 yrs**
1 ind	0	0.0084	0.0471	0.1279	0.2516	0.3723
50 inds	0	0.0645	0.3275	0.5362	0.6503	0.7118
100 inds	0	0.1230	0.4529	0.6285	0.7080	0.7509

Figure 7.3.3. Estimated extinction risks based on the 1991 to 2004 dataset for the GOM DPS. Quasi-extinction thresholds of 1, 50, and 100 individuals were calculated at 20 year intervals.

The above results relate to the estimated extinction risk of the GOM DPS as previously defined in 2000 plus the Penobscot River Atlantic salmon populations based on the population dynamics from 1980 to 2004 and 1991 to 2004 time series of data. The BRT decided that these measures provided the best proxy for the estimated extinction risk of the GOM DPS (as defined in section 6 of this Status Review) as a whole.

It should be noted that these estimates are calculated from the dynamics of the systems as determined by the influences of various factors (environmental, natural and hatchery demographics, genetic, etc.) during the time frame being examined. Specifically, the abundance measures that SPAZ is analyzing are the results of both natural spawning and hatchery supplementation. In recent times, potential future returns are removed from the population for broodstock purposes, as detailed in Section 5 of this Status Review. For the GOM DPS as previously defined in 2000, juveniles are removed from the river to form future broodstock sources. For the Penobscot River, returning adults are brought directly to the hatchery for spawning. In some years, the number of adults brought to the hatchery is greater than the number allowed to spawn naturally. Increased juvenile survival in the hatchery environment results in large numbers of juvenile fish available for stocking at a variety of life stages. This allows these hatchery broodstock to contribute to a greater proportion to the adult returns than would have occurred if all fish were allowed to spawn in the river naturally. From 1980 to 2004, approximately 8.2% of the returning adults were the results of naturally spawning or fry stocking. For the period

1991 to 2004, approximately 12.8% resulted from wild spawning or fry stocking. Without hatchery supplementation, the extinction risks estimated above would be even higher.

Section 8: Listing Factor Analysis

In accordance with Section 4 (a) of the ESA, the Services are required to analyze whether a species is endangered or threatened based upon any one or more of the following five factors: (A) the present or threatened destruction, modification, or curtailment of a species' habitat or range; (B) overutilization for commercial, recreational, scientific, or educational purposes; (C) disease or predation; (D) the inadequacy of existing regulatory mechanisms; or (E) other natural or manmade factors affecting the species continued existence. The purpose of this section is to synthesize available scientific information with respect to the factors of decline for the GOM DPS of Atlantic salmon as defined in Section 6 of this Status Review.

The BRT developed a listing factor matrix (Appendix 8) to help structure the analysis. Each stressor was identified, ranked by life stage, and categorized according to the number of populations (number of large rivers and number of small rivers) affected by each stressor.

However, it should be noted that these factors and stressors are not independent. In fact, some may be synergistic; some may be antagonistic; and, none are mutually exclusive. Similar assessments have been conducted for Atlantic salmon in the Northwest Atlantic (Cairns 2001) and in Maine specifically (NRC 2004). While this section of the Status Review does describe some direct causes of the present low abundance of the GOM DPS, the ultimate causes are not addressed; see Lackey (2003) for such a discussion relative to Pacific salmon in the Western U.S.

8.1 Present or Threatened Destruction, Modification, or Curtailment of Habitat or Range

While many of the historical unregulated water and land use practices that adversely impacted salmon habitat within the range of the GOM DPS have been eliminated, the legacy of these impacts to the physical, chemical, and biological structure of these rivers and streams can remain for decades. In addition, contemporary land and water use practices including forestry, agriculture, urbanization, flood control, water pollution, water withdrawal, and dams continue to substantially reduce the quantity and quality of Atlantic salmon habitat throughout Maine by (1) eliminating or degrading spawning and rearing habitat, (2) reducing habitat complexity and connectivity, (3) degrading water quality, and (4) altering ambient stream water temperatures. Current smolt population and survival studies strongly suggest that habitat related factors in freshwater may be significantly reducing smolt production in the GOM DPS (USASAC 2004).

8.1.1 Elimination or Degradation of Spawning and Rearing Habitat

Over the last 200 years, many land use and water use activities have eliminated or degraded significant portions of Atlantic salmon spawning and rearing habitat within the range of the GOM DPS. Major contributing factors include construction of dams, water withdrawals, sedimentation, and land use activities.

8.1.1.1 Dams

The greatest impediment to self-sustaining Atlantic salmon populations in Maine is obstructed fish passage and degraded habitat caused by dams (NRC 2004). In addition to direct loss of production habitat to impoundment and inundation, dams also alter natural river hydrology and geomorphology, interrupt natural sediment and debris transport processes, and alter natural temperature regimes (Wheaton et al. 2004). These impacts can have profound effects on aquatic community composition and adversely affect entire aquatic ecosystem structure and function. Existing riverine (lotic) aquatic communities upstream of a dam site are typically replaced by lacustrine communities following construction. Anadromous Atlantic salmon inhabiting the GOM DPS are not well adapted to these artificially created and maintained impoundments (NRC 2004). Conversely, other aquatic species that can thrive in impounded riverine habitat will proliferate, and can significantly change the prey resources available to salmon, as well as the abundance and species composition of competitors and predators (see Section 8.3 for a detailed review; NRC 2004).

Unnatural regulation of stream flows at hydropower projects (daily or seasonal store and draw, daily peaking and cycling, etc.) can also adversely affect salmon through stranding, redd dewatering, increased predation, interference with spawning or migratory behavior, increased embeddedness of spawning substrates, and compromised invertebrate production (Hunter 1992). In addition, trapping of gravel in impoundments and release of clear water downstream of dams can cause the winnowing of smaller, mobile grains from beds below dams, leaving only progressively coarser substrates. This process, termed armoring, may result in gravels becoming too coarse for use by spawning salmon (Kondolf 2000). Habitat and aquatic communities in reaches immediately below dams can also be affected due to the unnatural funneling of flows to particular segments of the dam (e.g., powerhouse or penstocks) at the expense of adjacent segments and associated habitat, or due to the depth of the water intake (e.g., deep/cold versus surface/warm).

The National Inventory of Dams Program lists 639 dams over four feet in height in Maine (Figure 8.1.1.1). Over half of these dams are located within the range of the GOM DPS. Dams less than four feet in height also exist within the range of the GOM DPS; however, a thorough inventory of these structures has not been conducted to date. The larger hydroelectric dams and storage projects within the GOM DPS are primarily located in the Penobscot, Kennebec, and Androscoggin watersheds.

There are at least 116 dams in the Penobscot River watershed alone (FERC 1997a). Of these, 24 operate under a FERC hydropower license or exemption, and 18 currently generate electricity while six others are operated to enhance generation at other facilities. One additional FERC hydropower project (Orono) is currently off-line but is slated for

Figure 8.1.1.1. Dams over four feet in height in Maine (data source: National Inventory of Dams Database).

rehabilitation. With the exception of several of the licensed West Branch Penobscot dams, and three unlicensed storage dams on the East Branch Penobscot, all of the larger dams in the basin are licensed to operate solely in a "run-of'the-river" mode (i.e., inflow generally equals outflow). However, daily flow manipulations originating in the West Branch system translate, albeit in progressively dampened fashion, to some daily variations in real-time inflow and outflow at main stem run-of-the-river dams.

While over 100,000 units of rearing habitat remains accessible in the Penobscot River watershed, historical and present day dams have eliminated or degraded vast, but to date unquantified, reaches of suitable rearing habitat. FERC (1997a) estimated that 27% (19 miles) of main stem habitat (i.e., not including the Stillwater Branch segment) is impounded by the five dams between head-of-tide and the confluence of the East and West Branches in Medway. On the West Branch, approximately 57% of the 98 river miles is impounded (USACOE 1990). Approximately 11% of the ±74 miles of the Piscataquis River main stem, 28% of the ±43 miles of the Sebec River tributary to the Piscataquis, and 8% of the ±25 miles of the Passadumkeag River (below natural barrier at Grand Falls) is impounded (USACOE 1990).

Furthermore, because hydropower dams are typically constructed in reaches with moderate to high underlying gradients, approximately 50% of available gradient in the main stem, and 41% in the West Branch, is impounded (USACOE 1990, FERC 1997a). Coincidently, these moderate to high gradient reaches, if free-flowing, would likely constitute the highest value as Atlantic salmon spawning, nursery, and adult resting habitat within the context of all potential salmon habitat within these reaches. Thus, in assessing the impacts of habitat modifications caused by hydropower projects, it is important to consider not only how much potential salmon habitat is "occupied", but also the specific locations of such occupations in relation to the natural river bottom profile and potential levels of habitat value to Atlantic salmon.

Compared to a natural hydrograph, the operation of dams in a store-and-release mode on the East Branch, and especially on the West Branch of the Penobscot River, results in reduced spring runoff flows, less severe flood events, and augmented summer and early fall flows. Such operations in turn reduce sediment flushing and transport and physical scouring of substrates, and increase surface area and volume of summer and early fall habitat in the main stem. Water drawn from impoundments in the West Branch often constitutes half or more of the streamflow in the main stem during the otherwise drier summer months (data analyzed from FERC 1996a).

The extent to which these streamflow modifications in the upper Penobscot watershed impact salmon populations, habitat (including migratory corridors during applicable seasons), and restoration efforts is unknown. However, increased embeddedness of spawning and invertebrate colonization substrates, diminished flows during smolt and kelt outmigration, and enhanced habitat quantity and, potentially, "quality" for non-native predators such as smallmouth bass (*Micropterus dolomieu*), are likely among the adverse impacts to salmon. Conversely, higher summer and early fall stream flows may provide some benefits to Atlantic salmon or their habitat within affected reaches, and may also

help mitigate certain potential water quality impacts (e.g., dilution of harmful industrial and municipal discharges).

There are at least 73 dams located in the Kennebec River watershed. Of these, 26 are licensed hydroelectric generating facilities and storage dams (MSPO 1993). The Kennebec River watershed is estimated to have over 100,000 units of suitable rearing habitat available for Atlantic salmon, though less than 10 percent of that habitat is presently accessible. The actual amount of habitat eliminated or degraded by the presence of dams has not been determined for the Kennebec River.

Similar to the Penobscot River, operation of hydroelectric storage dams on the Kennebec River results in lesser spring runoff flows, lesser severity of flood events, and augmented summer flows (FERC 1997b). Although Atlantic salmon do not presently occur in the Kennebec River due to the lack of upstream fish passage at the first main stem dam (see discussion of habitat connectivity later in this section), available habitat for Atlantic salmon is expected to be impacted by alteration of the natural hydrograph.

The Androscoggin River had more falls, rapids, and cataracts than any river of its size in Maine (DeRoche 1967). Dams now inundate the majority of rapids and falls. Historically, Atlantic salmon ascended the Androscoggin River upstream to Rumford Falls (DeRoche 1967), a natural falls about 80 feet high that prevented salmon from ascending the river further upstream. There are approximately 45 hydroelectric generating facilities located in the Androscoggin River watershed. In addition, there are roughly 40 dams four feet in height or higher present in the Androscoggin River watershed (NID 2005). DeRoche (1967) estimated approximately 90,000 units of rearing habitat exist in the Androscoggin River, though less than 10 percent of that habitat is presently accessible. The actual amount of habitat eliminated or degraded by the presence of dams has not been determined for the Androscoggin River.

Storage reservoirs in the Androscoggin River are used to regulate river flow in the Androscoggin River such that a consistent flow is provided in the summer months (FERC 1996b). However, large variations in flows also occur in the lower Andoscoggin River as a result of hydropower peaking operations. Regulation of flows in the upper river and hydropower peaking operations in the lower river are expected to impact available Atlantic salmon habitat in this watershed. Due to the lack of fish passage facilities at hydropower dams, however, Atlantic salmon can only access approximately 15 miles of the lower river (see discussion of habitat connectivity later in this section).

Many hydropower dams on the Penobscot, Kennebec, and Androscoggin Rivers also have bypassed reaches of natural river channel because river flows have been re-routed through forebays or penstocks. FERC often, but not always, requires flow allocations to these bypassed reaches. However, because these bypass flows are often based on establishing only a minimum level of habitat protection, and for a wide variety of indigenous aquatic life species (e.g., other sea-run fish species, resident fish species, macroinvertebrates) rather than just for salmon alone, they often do not result in an optimum habitat value for salmon. Thus, Atlantic salmon habitat is at least somewhat

degraded in many of these spillway bypass reaches of the larger rivers within the range of the GOM DPS.

Many small dams remain on smaller rivers within the range of the GOM DPS. Table 8.1.1.1 presents a summary of dams four feet and higher within the smaller watersheds of the GOM DPS (National Inventory of Dams database). Most of these dams do not generate hydroelectricity. Although these dams are significantly smaller than typical hydroelectric projects on larger river systems in Maine, they continue to impact substantial amounts of Atlantic salmon spawning and rearing habitat.

Table 8.1.1.1. Summary of dams four feet and higher and upstream fish passage conditions of smaller river basins within the range of the GOM DPS. Note: Penobscot, Kennebec, and Androscoggin watersheds are not included in this table.

Atlantic Salmon River	Total Suitable Rearing Habitat (1=100m^2)	Dam Name	Section or Tributary	Upstream Passage (Y/N)[1]
Dennys River	2,152	Meddybemps	Meddybemps Lake Outlet	Yes
		Cathance Lake Dam	Cathance Stream	Yes
East Machias	3,006	Gardner Lake Dam	Chase Mill Stream	Yes
Hobart Stream	85	Holmes Mill Dam	Main stem	No
Little River	Unknown	Lower Reservoir Dam	Main stem	No
		Upper Reservoir Dam	Main stem	No
Medomak River	2,386	Waldoboro Dam	Main stem	Yes
		Washington Pond Dam	Little Medomak Brook	No
Narraguagus River	6,014	Cherryfield Ice Control	Main stem	Yes
		Bog Brook Dam	Bog Brook Flowage	Yes
Orange River	20	Mainstream Dam	Main stem	No
		Lubec Water & Elec. Light CO.	Orange River Flowage	No
		Mill Dam	Un-named Tributary	No
Orland River	165	Orland Village Dam	Narramissic River	Yes
		Alamoosook Dam	Narramissic River	Yes
		Toddy Pond Dam	Un-named Tributary to Alamoosook	Yes
		Craig Pond Dam	Craig Brook	No
		Phillips Lake Dam	Phillips Lake Stream	Yes
Passagassawakeag River	331	Holmes Mill Dam	Main stem	No
		Ellis Dam	Main stem	No
		Sanborn Pond Dam	Un-named Tributary	No
		Smith's Mill Pond Dam	Un-named Tributary	No
Pemaquid River	1,014	Bristol Mills Dam	Upper Main stem	Yes
Pleasant River		Pleasant River Lake Dam	Pleasant River Outlet	Yes

Atlantic Salmon River	Total Suitable Rearing Habitat (1=100m^2)	Dam Name	Section or Tributary	Upstream Passage (Y/N)[1]
Sheepscot River	2,797	Head of Tide	Main stem	Yes
		Coopers Mill Dam	Main stem	Yes
		Sheepscot Lake Dam	Sheepscot Lake Outlet	No
		Trout Brook Dam	Trout Brook	Yes
		Dinsmore Dam	West Branch	No
		Three Corners Pond Dam	Un-named Tributary	Unkown
		Alna WCS	Un-named Tributary	No
		Clary Lake Dam	Clary Lake Outlet	No
St. George River	10,209	Trues Pond Dam	Main stem	No
		Davistown Dam/ Lake St. George	Main stem	No
		Kingdom Bog Dam	Unamed Trib.	No
		Stevens Pond Dam	Unamed Trib.	No
		Lermond Pond Dam	Mill Stream	No
		Casket Mill Dam	Mill Stream	No
		Alford Lake Dam	Mill Stream	No
		Fish Pond Dam	Quiggle Brook	No
		Mill Pond Dam	Allen Brook	No
		Ruffingham WMA Dam	Bartlett Stream	No
Tunk Stream	585	Barbless Pond	Barbless Stream	No
		Unamed	Un-named Tributary	No
Union River	2,594	Ellsworth	Main stem	Yes[2]
		Graham Lake Dam & Flood Control	Main stem	No
		Branch Pond Dam	Branch lake Stream	No
		Ellsworth Water Co. Dam	Branch lake Stream	No
		Patten Brook Dam, Lower Pond	Patten Stream	Yes
		Green Lake	Reeds Brook	No
		Lower Lead Mountain Dam	Starvation Branch	No
		Donnell Pond Dam	Donnell Brook	Yes
		Lyle Frost WMA Dam	Little Bog River	No

[1]Passable under most conditions.
[2]Trap and Truck

8.1.1.2 Water Withdrawals

Water withdrawals for agricultural irrigation or other purposes can directly impact Atlantic salmon spawning and rearing habitat (MASTF 1997). Water extraction has the potential to expose or reduce salmon habitat. Water quantity and quality can be affected by the withdrawal of water for irrigation and other purposes. Adequate water quantity and quality are critical to all life stages of Atlantic salmon, and for specific behaviors especially adult migration and spawning, fry emergence, and smolt emigration. Survival

of eggs, fry, and juveniles are also mediated by streamflow. Juvenile salmon, present in the stream throughout the year, are adapted to survive high flows by seeking refuge in the substrate. However, it is low flows that constrain available habitat and limit populations. During summer and winter, the two periods of low flow annually, juvenile salmon survival is directly related to discharge (Gibson 1993), with better survival in years with higher flows during these seasons (Ghent and Hanna 1999). Thus, summer water withdrawals have the potential to limit carrying capacity and reduce parr survival. In addition, withdrawals may dewater redds thus reducing egg survival; reduce flows in summer and impede adult migration; and reduce spring discharge and extend smolt emigration.

The extent of water withdrawal and its effect on Atlantic salmon habitat in the main stem areas of the Penobscot, Kennebec, and Androscoggin Rivers are largely unknown. Because of the large size of these watersheds, there are a variety of consumptive water uses, including municipal water supplies, snow making, mills, golf course and agricultural irrigation, and industrial cooling. Depending upon the location of current water uses, impacts to Atlantic salmon habitat may be occurring in headwater areas and tributaries of these watersheds. The extent and potential of these uses to affect Atlantic salmon populations has not been completely evaluated. Population growth and development in these watersheds is expected to accelerate in future years, especially in the mid-coast region likely increasing the demand for consumptive water use.

Increased levels of agricultural irrigation have been occurring throughout the range of the GOM DPS for several years. The Maine Department of Agriculture and the Natural Resource Conservation Service have funded projects designed to enhance potato production in central Maine (Dan Kusnierz, Penobscot Indian Nation, personal communication). These projects include irrigation systems and pond construction designed to capture water without drawing water directly from stream channels. In addition, commercial wild blueberry growers irrigate with water withdrawn from Pleasant, Narraguagus, and Machias river watersheds. Agricultural water use is likely to grow based on industry projections of expanding berry production and processing. Approximately 6,000 acres of blueberries are irrigated annually. As blueberry growers reportedly plan to significantly increase production in the future, more water will be needed for irrigation, frost protection, and berry processing (NMFS and FWS 2004).

The State of Maine and its partners have completed a water use management plan (WUMP) for the Narraguagus and Pleasant Rivers and for Mopang Stream (MSPO 2001). As a result of the WUMP, there has been a net reduction in the number of large growers withdrawing water directly from streams covered under the WUMP (NMFS and FWS 2004). However, numerous smaller wild blueberry growers continue to rely on direct water withdrawals from rivers to meet their irrigation needs. In recent years, one of the larger wild blueberry growers has moved away from withdrawing water directly from rivers in these watersheds to relying on groundwater withdrawals to meet their needs. Ground water withdrawals have the potential to affect stream flow (Winter 1995). The effects of existing wells are currently being monitored.

8.1.1.3 Sedimentation

For successful incubation, gravel must be sufficiently free of fine sediment so that the flow of water through the gravel is adequate to bring dissolved oxygen to eggs and carry off metabolic wastes (Kondolf 2000). The degree to which fine sediments surround coarse substrates within the streambed is referred to as embeddedness (Sylte and Fischenich 2002). Anthropogenic sedimenation loading can lead to increased embeddedness of spawning and incubation substrates. Permeability, a measure of water flow through substrate, is reduced in embedded spawning gravels leading to lower dissolved oxygen rates and greater concentrations of metabolic wastes around incubating eggs (Moring 1982, Tappel and Bjornn 1983, Chapman 1988, Kondolf and Wilcock 1996). For successful incubation, gravel must be sufficiently free of fine sediment so that the flow of water through the gravel is adequate to bring dissolved oxygen to eggs and carry off metabolic wastes (Kondolf 2000).

Juvenile survival is also affected by increased deposition of sediment within stream channels. The interstitial spaces among cobble, boulder, and gravel are shelter for juvenile salmon. Sediment in these spaces reduces the carrying capacity of a stream reach (Bjornn et al. 1974, Bjornn et al. 1977). Increased embeddedness may block juvenile salmon from sheltering beneath substrates during cold temperatures and lower overwinter survival (Atkinson and Mackey 2005). The loss of shelter in interstitial gravel and cobble spaces can result in increased predation (Cordone and Kelley 1961, Bjornn et al. 1974, Roussel et. al. 2004). Further, increased substrate embeddedness can result in decreased habitat complexity, reducing visual isolation among individual fish, creating larger territories and lower densities of fish (Atkinson and Mackey 2005).

In addition, anthropogenic sedimentation can fill pools, decreasing depth and total area, thus reducing the amount of habitat available for juveniles and adults (Cordone and Kelley 1961). Excess sedimentation in pools has been cited as a reason for numerous salmonid population declines (Saunders and Smith 1965, Peters 1967, Elwood and Waters 1969, Barton 1977). Adult Atlantic salmon hold in pools and deadwaters within the river system. These deeper waters hold pre-spawn and spawning fish in the summer and fall and kelts (post-spawn fish) through the winter prior to their downstream migration in the spring.

Sedimentation can adversely affect benthic macroinvertebrate populations (Bjornn et al. 1974, Bjornn et al.1977, McClelland and Brusven 1980). The insect orders affected are often those most readily available to foraging fish (Waters 1995). Reduced food supply may further cause fish to defend larger territories, decreasing the density of fish. Increased substrate embeddedness can result in decreased habitat complexity, reducing visual isolation among individual fish, creating larger territories and lower densities of fish (Atkinson and Mackey 2005).

In 2004, the MASC resurveyed a number of sites on the Narraguagus and Dennys Rivers to compare cobble embeddedness measure with those taken in 1993. Preliminary analysis indicates substrate embeddedness on the Narraguagus River may have increased

over the eleven-year period (Atkinson and Mackey 2005). Interstitial space index, the inverse of imbeddedness, at the sites seems to have declined from 1993 to 2004.

Sedimentation from a variety of sources continues to alter habitat in the GOM DPS and compromise the capability to support Atlantic salmon (65 FR 69459). Identified anthropogenic sediment sources are numerous with recent inventories identifying over 800 NPS sites on five Downeast Rivers and over 400 NPS sites on the Sheepscot River (NMFS and FWS 2004). Non-point sources include road construction and poor maintenance, improperly constructed culverts, unstable bridge abutments, improper road ditching, winter sand and salt, poor agricultural practices, recreational all terrain vehicles (ATVs) trails and fords, timber harvest activities not conducted in accordance with BMPs, and dredging. While there have been a number of NPS surveys conducted within the range of the GOM DPS, the full extent of sedimentation and embeddedness is not well documented. Several stakeholders including Project SHARE, the Sheepscot Valley Conservation Association, Narraguagus River Watershed Council, the PIN, Dennys River Watershed Council, and others continue to work to identify and remediate NPS sites within the range of the GOM DPS (NRWC 2003, DRWC 2005).

Excessive removal of riparian vegetation can accelerate erosion and sedimentation and contribute to thermal loading (Swanston 1991). Historically, timber harvesting activities significantly altered Atlantic salmon habitat through the direct and indirect effects of timber removal (Chamberlin et al. 1991), transport (Furniss et al. 1991, Sedell et al. 1991), and subsequent processing of wood products (Thut and Schmiege 1991). Historical practices such as log driving, channel clearing, and large-scale clear cutting have largely been eliminated. However, a recent incident on the Dennys River highlights the potential for activities related to timber harvesting to result in NPS pollution when not conducted in accordance with BMPs. In June of 2004, an evaluation of a logging operation in Dennysville found a sediment plume covering 50% of the width of the Dennys River (DRWC 2005). The sediment discharge was the result of a skidder crossing an intermittent stream in a very wet area with silt/loam/clay soils. The event was likely caused by failure to use recommended BMPs during the harvest activity (DRWC 2005).

The legacy of past, large-scale forestry operations continues to affect Atlantic salmon habitat within the range of the GOM DPS (NRC 2004). Most forested land in Maine has been subjected to one or more cycles of logging (NRC 2004). Historical forest operations have resulted in significant and sustained changes to aquatic ecosystems (NRC 2004). Riparian cutting increased sedimentation and diminished large woody debris (LWD) supply. Installation of “splash” dams, channel clearing, and dumping mill waste and sawdust diminished the complexity (see Section 8.1.4) of microhabitats throughout many rivers. While current forest management activities do not appear to represent a significant threat under current management measures and harvest practices (NRC 2004), the effects from past practices are not fully remediated.

8.1.1.4 Land Use

Changing land-use patterns, particularly development and land conversion creates a number of issues that may affect spawning and rearing habitat. Increased development and population growth results in land clearing and construction of infrastructure such as roads, road crossings, and buildings. These activities can alter and disrupt the hydrological process in the system and result in a decline in water and habitat quality (Booth et al. 2002). For example, increasing the amount of impervious surface (e.g. roads, parking lots) in a watershed can alter hydrologic regimes, increase erosion, and increase pollutant loads entering streams and rivers. Land management activities, particularly land clearing for agriculture, development, and timber harvest, have the potential to impact geomorphological and riparian processes (Boyer et al. 2003, NRC 2004).

The construction of new roads increases access into relatively undisturbed and previously inaccessible areas. Roads are often built in association with logging, agriculture, and the development of homes or industrial or commercial projects. All these activities can result in a number of ecological effects including decreased habitat quality and connectivity. Roads can alter many ecological functions and characteristics including the pattern of runoff and surface water flow, sedimentation and increased nutrient loading and chemical contaminants (Trombulak and Frissell 2000). Numerous studies have correlated declines in the ecological health and habitat quality of streams and rivers in relation to the roads (Trombulak and Frissell 2000). Roads can result in the direct transfer of sediment and other material to streams and other water bodies at crossing sites. Roads and bridges can directly alter the development of stream channels. Changes in land cover and land and water use can also result in excessive nutrient enrichment of a river. Depending on a large number of factors, the effects of roads on the ecological health of a landscape can be quite severe (Trombulak and Frissell 2000).

Population growth and development in Maine has accelerated in recent years, especially in the mid-coast region. The Maine State Planning Office (SPO) projects that the southern, mid-coast and Penobscot regions of Maine will continue to experience changes from current rural land-use to urban/suburban in the next several decades (Figure 8.1.1.4). Associated with increased population growth, land conversion and development are increased infrastructure needs including road construction and resource demands such as increased water use and water pollution control and treatment.

Figure 8.1.1.4. Demographic patterns in Maine. Reproduced with permission from the Maine State Planning Office.

8.1.2 Loss of Habitat Complexity and Connectivity

Atlantic salmon require a complex variety of well connected habitat types to complete their life history (Klemetsen et al. 2003). The following sections discuss the roles of habitat complexity and connectivity to Atlantic salmon and historical and present impacts to these important habitat features.

8.1.2.1 Habitat Complexity

Diverse habitats support diverse species assemblages and communities (Smith 1996). This diversity contributes to sustained production and provides stability for the entire ecosystem (Taylor 1990). Further, habitat diversity can also mediate biotic interactions such as competition (Hartman 1965) and predation (Schlosser 1988). Attributes of habitat diversity include a variety and range of hydraulic parameters (Kaufmann 1987),

the abundance and size of wood (Bisson 1987), and a variety of substrate types and sizes (Sullivan et al. 1987).

8.1.2.1.1 Large Woody Debris and Boulders

Large instream structures such as boulders, large woody debris (LWD), and organic debris (e.g., root wads) can influence sediment sorting and storage, spacing of pool-riffle sequences, and overall channel geometry. Thus, these structures are important for the formation and maintenance of the variety of habitats that juvenile Atlantic salmon require. Structural elements affect channel processes at all scales from distribution of bed materials to valley formation. At a local level, structural controls can create scour conditions that form and maintain pools. At a reach level, LWD can influence pool-riffle sequencing, bank erosion and bar formation. At a valley level, LWD can influence interaction between rivers and their floodplains.

LWD may be important for Atlantic salmon during several life-history stages. Nislow et al. (1999) found that survival of salmon fry in small streams in Vermont was strongly correlated with the availability of lateral, low-velocity microhabitats and that LWD addition increased the availability of these habitats. LWD may be even more important for older juveniles because they use instream cover, including LWD, particularly during winter (Cunjak et al. 1998). Recent assessments of Atlantic salmon populations in Maine (USASAC 2005) indicate that survival of juveniles in the winter prior to their emigration as smolts is very low compared to populations in other regions, and may constitute a bottleneck to population recruitment. In winter, salmon require habitat that provides adequate shelter from adverse physical conditions and protection from endothermic predators (e.g., otter; Cunjak et al. 1998, Valdimarsson and Metcalfe 1998, Whalen et al. 1999). Thus, availability of “high quality” winter habitat may influence salmon survival during this critical life history stage. By increasing habitat complexity, LWD may increase overwinter survival (Quinn and Peterson 1996, Solazzi et al. 2001).

Most rivers in Maine were historically used for log drives. Streams were reportedly channelized and meanders removed in order to transport logs to sawmills (Warner and Porter 1960, Frost et al. 2004). Large instream structures such as boulders were removed where they might obstruct or hinder the downstream transport of timber. An inventory of historic impacts to habitat, prepared for Project SHARE, details a wide variety of in-stream channel changes on the Machias River (Abbott 2004). Modifications include removal of mid-channel boulders on the Narraguagus and Machias Rivers, diking along lower reaches of the Machias River, and channel modifications on the Sheepscot River.

Presently, large woody debris is removed at various hydroelectric dams in the Penobscot, Kennebec, and Androscoggin River watersheds. Woody debris build-up on the trashracks is removed by dam owners to facilitate hydroelectric generation and then typically transported to land fills or burned on-site. Development and other land use activities (e.g., forestry) in riparian corridors may also be limiting LWD supply.

8.1.2.1.2 Channel Geomorphology

The natural pattern of annual flows in Maine rivers include (1) low flows during the months of July, August, and September; (2) increased flows during October and November as a consequence of autumn rains; (3) a period of winter low flows, particularly in February; (4) peak flows between late March and mid April; and (5) relatively high flows continuing through mid May. These patterns of flow are responsible for maintaining the habitat structure within the river channel. The volume and timing of high flows facilitate effective sediment transport, cleansing fine sediment from juvenile and spawning habitat, building gravel bars, and maintaining diversity in channel morphology. The geomorphologic process of sediment transport and deposit are critical to maintaining productive Atlantic salmon habitat (Hill et al. 1991, Leopold et al. 1992, McBain and Thrush 1997).

Many reaches of rivers within the range of the GOM DPS display high channel width to depth ratios indicating stream channels are wide and shallow (NMFS and FWS 2004). While hydraulic geometry relations for Maine "salmon rivers" are unique, they are within the range of other studies in the eastern U.S. (Dudley 2004). Channel morphology has been altered by changes in land use, construction of dams, channelization, and log drives. Shallow channels may have resulted from disturbance or are a function of bedrock geology. Channels with large width to depth ratios tend to experience more rapid water temperature fluctuations as cooling and heating occurs more quickly than in narrow deep channels (Cunjak et al. 1998). Changes in channel geometry can also increase armoring and embeddedness as wider channels could decrease bed mobility (e.g., reduce sediment transport).

Alterations of the physical instream habitat have been documented on a number of rivers in Maine. For example, an inventory of historic impacts to habitat, prepared for Project SHARE, details a wide variety of instream channel changes on the Machias River (Abbott 2004). Documented alterations on the Machias River include widening at the outlet of First Machias Lake, diversions below Holmes Falls, and areas of the river bottom covered with slabs of wood. Most of these impacts appear to have occurred prior to stringent regulations that significantly limit these activities today.

8.1.2.2 Habitat Connectivity

An important consideration for maintaining aquatic and riparian ecosystem functions is the degree of spatial and temporal connectivity within and between watersheds (Naiman et al. 1992). Connectivity is the capacity of an ecosystem to allow a species "to migrate at the appropriate time between links in the habitat chain" to complete their life cycle (Lichatowich et al. 1995). Lateral, vertical, and drainage network linkages are critical to aquatic system function. Important connections within watersheds include linkages among headwater tributaries and downstream channels as paths for water, sediment, nutrients, and disturbances (NMFS 1996). Further, linkages among floodplains, surface water, and ground water systems as exchange for water, sediment and nutrients are also important (NMFS 1996). Unobstructed physical and chemical paths to areas critical for

fulfilling life-history requirements of aquatic and riparian dependent species must also be maintained to ensure ecosystem stability.

As a migratory species, Atlantic salmon must be able to access spawning and rearing habitat and safely migrate back to the ocean in a timely manner in order to complete their life cycle. Lack of habitat connectivity affects both the abundance and distribution of Atlantic salmon populations, as well as that of several other native sea-run species that salmon co-evolved with (e.g., American shad, alewives, sea lamprey). Both man-made barriers (e.g., dams, culverts) and natural barriers (e.g., beaver dams, debris jams) currently fragment Atlantic salmon habitat within the range of the GOM DPS.

8.1.2.2.1 Dams

Probably the most significant contributing factor to the loss of habitat connectivity within the range of the GOM DPS is the historical and contemporary presence of artificial dams, especially on the larger river systems (NRC 2004). Historically, dams were a major cause of the decline of Atlantic salmon runs in many Maine rivers and streams (Baum 1997). Dams were constructed to produce electricity, operate mills, transport logs, control flooding, and as ice control structures. Dams were constructed on salmon rivers in Maine as early as the 1700s. By the late 1800s, most organized towns in Maine diverted flowing waters and utilized hydro-power to facilitate commerce (Wells 1869). By the mid 1900s, practically every significant salmon river in Maine had at least one impassable dam. Typically, most dams on smaller rivers within the range of the GOM DPS were not built to generate electricity. In the Penobscot, Kennebec, and Androscoggin Rivers, however, many dams that were initially constructed for log driving and turning sawmills were later redeveloped to generate electricity. New sites on these rivers were also developed specifically for generation, primarily during the early to mid-1900s.

By blocking access to spawning and rearing habitats, dams that lack any upstream fish passage completely disrupt the life cycle of Atlantic salmon, leading to extirpation of self-sustaining runs in all reaches upstream of the dam. Even when upstream passage is available and adults are able to pass above dams and successfully reproduce, the impoundments behind these dams can confuse smolts during emigration, increase the energetic costs of their movements, slow net downstream progress, and increase predation (NRC 2004). Various researches have identified a “smolt window” or period of time in which smolts must reach estuarine waters or suffer irreversible effects (McCormick et al. 1999). Late migrants lose physiological smolt characteristics due to high water temperatures during spring migration. Delays in migration, such as those that occur at dams, may reduce smolt survival (McCormick et al. 1999). Even where formal upstream and downstream fish passage facilities have been installed at dams, passage inefficiencies and delays still occur at biologically significant levels at each facility. Incremental losses of pre-spawn adults, smolts, and kelts rapidly accumulate where multiple obstructions exist between the ocean and the higher quality salmon production reaches. The cumulative effects of these losses have not been well studied in Maine;

however, studies from the northwestern U.S. suggest that cumulative losses are very important in explaining current salmon population trends.

Upstream Fish Passage

The Penobscot, Kennebec, and Androscoggin River watershed have multiple hydroelectric dams. Most hydroelectric dams on the Penobscot River presently have upstream fish passage facilities; exceptions include Stillwater, Orono, Milo and Sebec. Of the over 100,000 metric units of potentially available rearing habitat in the Penobscot River watershed, approximately 80% is presently accessible to Atlantic salmon (USFWS 2004; Figure 8.1.2.2.1a). However, salmon must pass several main stem dams to access most reaches (Figure 8.1.2.2.1b). For example, 76% of all accessible habitat units are above at least four dams. Furthermore, of the habitat judged to be of high enough quality to produce two or more smolts per unit (versus between one to two smolts per unit for lower "quality" habitat reaches such as the lower main stem), 100% is above at least four dams, and an estimated 51% is above at least five dams.

The West Branch of the Penobscot River is currently inaccessible to anadromous fish because no upstream fish passage facilities exist on the four lowermost dams in the West Branch. This excludes Atlantic salmon from approximately 28,000 units of rearing habitat within the West Branch (USFWS 2004). Even if fishways were built at these four lowermost dams, the first significant reach with habitat suitable for Atlantic salmon would still lie above 10 total dams. While the loss of connectivity to the West Branch is clearly important from the strict perspective of production potential, the fact that an entire major subdrainage has been eliminated may further elevate the significance of this loss when viewed from the metapopulation perspective. As with many major tributaries of the Penobscot, the West Branch likely represented a unique combination of watershed level factors (e.g., topography, hydrology, basic water chemistry, and nutrient supply) that distinguished it from the East Branch, Piscataquis, or Mattawamkeag. Thus, the importance of having the West Branch available to the GOM DPS metapopulation of salmon, while unknown, could be significant at this broader scale (see Section 3.3, Habitat Availability, Accessibility, and Metapopulation Structure).

Upstream fish passage for Atlantic salmon had not been available for over 100 years in most of the Kennebec River. However in July 1999, the first hydroelectric dam (Edwards) on the Kennebec River was breached to allow anadromous fish to access 17 miles of spawning and rearing habitat. In the spring of 2006, upstream fish passage facilities were installed at the Lockwood Dam (currently the lowermost dam in the Kennebec) pursuant to the "Lower Kennebec River Comprehensive Hydropower Settlement Accord"; passage consists of a fish lift with trap and truck facilities for transporting anadromous fish above one or more additional dams, up to the site of the Abenaki Dam on the main stem and the Madison Electric Dam on the Sandy River (a major tributary to the Kennebec River with a large amount of suitable salmon habitat). A fish pump has been installed at the Ft. Halifax Dam on the Sebasticook River. However, this technology has not been demonstrated to successfully pass upstream migrating Atlantic salmon. Both the Ft. Halifax and Madison Electric dams are also currently being studied for removal.

Thus, only one mainstem dam on the Kennebec currently has upstream fish passage facilities for Atlantic salmon, although over 100,000 metric units of rearing habitat exist there (USFWS 2004). While some salmon rearing habitat is now available in the restored reach below Lockwood, the vast majority of salmon habitat (nearly 90%) in the Kennebec River watershed is located above Lockwood.

Based upon various biological triggers established by state and federal resource agencies in the above referenced Settlement Accord, the next main stem dam upstream of Lockwood (HydroKennebec) may not have upstream fish passage facilities installed until 2010 at the earliest, and the last dam with upstream habitat may not have fishways until 2020. Even after fish passage facilities are installed in the Kennebec River in accordance with this plan, Atlantic salmon will need to pass at least six main stem dams (Lockwood, Hydro-Kennebec, Shawmut, Weston, Abenaki, and Anson) in order to access 50% of available rearing habitat in the Kennebec River (Figure 8.1.2.2.1.c).

DeRoche (1967) estimated that the Androscoggin River watershed contains over 90,000 metric units of rearing habitat for Atlantic salmon. Presently, only the lower three dams on the main stem Androscoggin River have installed upstream fishways. The fourth dam on the river (Lewiston Falls) does not have installed fish passage facilities. Approximately 90% of all suitable rearing habitat is located upstream of Lewiston Falls; thus, practically all suitable rearing habitat in the Androscoggin River watershed is not currently accessible to Atlantic salmon.

Small river systems within the range of the GOM DPS have over 50 dams four feet high or higher. Main stem dams on the St. George River, Little River, Passagassawakeag, and Tunk Stream (historical salmon rivers in Maine) do not have upstream passage facilities; thus, the loss of habitat connectivity in these rivers is undoubtedly affecting the GOM DPS. Dams located on tributary streams of Atlantic salmon rivers are also likely affecting water quality, hydrology, and ecology of the river's main stem.

Among rivers within the range of the GOM DPS with hydropower dams that have one or more formal passage facility, most of the current understanding of fish passage efficiency comes from studies on the Penobscot River. Radio telemetry and other tracking studies by the MASC and various hydropower project licensees have shown wide variation in site-specific upstream passage success, depending on the dam location and the environmental conditions (e.g., temperature, hydrology) during the year of study. For example, at the Veazie Dam, the first encountered by adult migrants, passage success of radio tagged Atlantic salmon ranged from 44% in 1990 to 89% in 1992, and averaged 68% over five years of study in the late 1980s and early 1990s (Dube 1988, Shepard 1989a, Shepard and Hall 1991, Shepard 1995). Untagged control fish passed at an average rate of 46% (13 of 28) over two years of study (Shepard 1995). Shepard (1995)

Figure 8.1.2.2.1a. Cumulative percentage of Atlantic salmon rearing habitat within selected reaches of the Penobscot River watershed. Note: Reaches delineated by hydropower dams.

Figure 8.1.2.2.1.b. Current proportion of accessible Atlantic salmon habitat above dams in the Penobscot River watershed.

Figure 8.1.2.2.1.c. Cumulative percentage of Atlantic salmon rearing habitat within selected reaches of the Kennebec River watershed. Note: Reaches delineated by hydropower dams; as of Spring 2006, trap and truck passage above Lockwood.

hypothesized that warm water temperatures during certain study years contributed to some of the low passage success rates observed at Veazie.

At Great Works Dam, the next dam upstream of Veazie, passage success ranged from 38% in 1990 to 95% in 1989, and averaged 81% over five years of study (Dube 1988, Shepard 1989a, Shepard and Hall 1991, Shepard 1995). At Milford Dam, the next dam upstream, success ranged from 86% in 1987 to 100% in 1990, and averaged 90% (56 of 62) over five years of study (Dube 1988, Shepard 1989a, Shepard and Hall 1991, Shepard 1995). At the West Enfield Project, located 20 river miles upstream of Milford, upstream passage success was at least 90% over several years of study.

In addition to passage success information, these radio tag studies collectively report a wide range in time needed for individual salmon to pass various dams once detected in the vicinity of a spillway or tailrace. The yearly pooled median passage time at Veazie Dam ranged from 4.7 days to 33.2 days over five years of study, while the total range of individual passage times over this study period was 0.5 days to 99.5 days (Shepard 1995).

Passage delays at Great Works and Milford dams were substantially less than that observed at Veazie. At Great Works, the year-specific median passage time ranged from 1.4 to 2.7 days over four years of study, while the total range of individual smolt passage times over the entire study period was 0.3 days to 30.4 days (Shepard 1995). Passage delays observed at Milford were similar to those observed at Great Works (Shepard 1995). Due to small sample sizes, varying release locations among study years, and other experimental design factors, cumulative upstream passage success for the lower three dams on the Penobscot River (Veazie, Great Works, and Milford) is difficult to extract from these radio tag studies. However, in 1988 and 1989, respectively, 40% and 63% of study fish that were available below the Veazie Dam successfully passed both Veazie and Great Works dams (Shepard 1995). Applying the average passage success of 90% over five years of site-specific study at Milford (see above), one could grossly estimate the three-dam passage success rate at 36% in 1988 and 57% in 1989.

The MASC tagged several hundred Atlantic salmon adults captured at the Veazie Dam fishway trap with Passive Integrated Transponder (PIT) tags from 2002 to 2004. This study monitored the date and time of passage with tag detectors located at the entrance and exit of the upstream fishway(s) at five main stem and five major tributary hydropower dams in the Penobscot watershed (Beland and Gorsky 2004, MASC unpublished data). Of the 379 total salmon tagged at Veazie in 2002, only 21% (78 fish) also passed the Mattaceunk Project fishway on the main stem, some 50 miles and four additional dams upstream. Less than 1% (3 fish) passed above the Guilford Dam on the Piscataquis River tributary, six additional dams upstream. The percentages in 2003 were 9% (41 of 461) and less than 1% (1 of 461) for Mattaceunk and Guilford dam passages, respectively. In 2004, 19% (142) of the 709 PIT tagged salmon passed Weldon and less that 1% (6) passed Guilford Dam. Many factors affect these results. Most important is homing motivation with many of the study fish being hatchery smolts stocked below Weldon or Guilford dams as these fish would not be expected to pass the most upstream dams. Nevertheless, proportions of adults reaching two key upriver spawning reaches

(East Branch Penobscot River and Piscataquis River above Guilford) are less than would be expected based on the proportion of available production habitat and numbers of fry stocked in those reaches.

Beland and Gorsky (2004) also reported a significant percentage of adult Atlantic salmon (15 to 24%) that, once reaching the vicinity of either the West Enfield Dam on the main stem or the Howland Dam at the mouth of the Piscataquis River (located within one river mile of each other), passed both fishways at least once prior to selecting a final course and continuing further upstream. Recognizing that part of this apparent indecision could in part be a natural result of salmon encountering a major hydrological division in the watershed, it may also be due in part to the presence of two artificial barriers in the immediate vicinity.

Downstream Fish Passage

Most hydroelectric projects within the range of the GOM DPS are located in the Penobscot, Kennebec, and Androscoggin River watersheds. With the exception of the West Branch Penobscot dams, most operating hydropower projects in the Penobscot River watershed have some form of downstream fish passage facilities installed. However, many of these facilities are informal, interim in nature, or otherwise would not meet current USFWS or NMFS fishway prescription criteria. No permanent downstream passage facilities are available for Atlantic salmon at any hydroelectric dam on the Kennebec River, while only the lower three dams on the Androscoggin River have downstream passage. As such, most studies of downstream bypass facility efficiency within the range of the GOM DPS have occurred in the Penobsot watershed, and, overall, downstream systems have received less study than upstream facilities (USASAC 2005).

Downstream passage system collection efficiency (percent of fish arriving at forebay/spillway that find and use facility) and total site passage survival (total percent survival past dam, regardless of path chosen) vary widely among sites, within years, and across years at the same study site (USASAC 2005). Each hydroelectric dam equipped with downstream passage is unique in design, location of turbine intakes, turbine types, passage system design, spillway type, forebay hydraulics and physical characteristics, and overall river hydrology. Variations in river flow and turbine discharge at the time of study also significantly affects downstream passage efficiency rates. Combinations of these factors and across year environmental variability during the smolt and kelt migration periods, result in downstream passage success being highly year- and site-specific. These factors make the study of downstream passage especially complex, and results are often open to widely varying interpretation.

Two hydropower projects on the Penobscot, Mattaceunk (fifth main stem dam above tidewater) and West Enfield (fourth main stem dam above tidewater), have received the most site-specific study among all dams within the range of the GOM DPS. Most of these studies were conducted by project licensees and used radio telemetry. At the Mattacunk Project, downstream passage collection efficiency for hatchery smolts, over seven years of study in the 1990s, ranged from 17% to 59% (GNP 1989, GNP 1995, GNP 1997, GNP 1998, GNP 1999). Virtually all other study fish that passed this dam used the

turbine route, as there was no spill during any of the study periods. Downstream passage efficiency for wild smolts ranged from 28% to 37% (GNP 1995, GNP 1997). At the West Enfield Dam, downstream passage collection efficiencies for hatchery smolt over five years of study in the early 1990s ranged from 2% to 49% (Bangor-Pacific Hydro Associates (BPHA) 1993a, 1993b, 1994; Hall and Shepard 1990a; Shepard 1991a, 1991b). Downstream passage efficiency for wild smolts was 14% in one year of study (BPHA 1994). Most other passages at this dam were via turbines, although 8% in 1990 and 28% in 1991 passed via the spillway.

Multiple dam passage studies of smolt were conducted in 1989 and 1990 by the licensee for several main stem dams. In 1989, net smolt survival over the three lower river main stem dams (Milford, Great Works, Veazie) and the intervening habitat was between 30.5% and 61% (Shepard 1991c). The wide range in these figures reflects the uncertainty as to how to classify tagged smolts that are detected at one or more upstream detection arrays, but then are not detected at the lowermost array at the last dam, where gaps in detection coverage were reported. In 1990, the net smolt survival over four dams (West Enfield, Milford, Great Works and Veazie for those choosing the main stem route, or West Enfield, Stillwater, Orono, and Veazie for those choosing the Stillwater Branch route) and the intervening habitat was between 38% and 92% (Shepard 1991c), again depending on the manner in which undetected fish were treated along the course of the study reach.

Spicer et al. (1995) investigated long distance survival of smolts in the Penobscot. Of 32 radio-tagged hatchery smolts released below the Howland (Piscataquis) and West Enfield dams, only one was recorded as reaching and passing the first downstream dam encountered (Milford), about 33 km from the release site. This same smolt was tracked with mobile gear another 7 km, to the reach between the Great Works and Veazie dams, but was not detected at a stationary array located below the Veazie Dam.

The potential for delays in the timely passage of smolts encountering hydropower dams is also evident in some of these tracking studies. At the Mattaceunk Dam, the average time needed for hatchery smolts to pass the dam, after being detected in the forebay area, was 15.6 hours (range 0 to 72 hours), 39.2 hours (range 0 to 161 hours), 14.6 hours (range 0 to 59.4 hours) and 30 hours (range 0.2 to 226 hours) in four different study years (GNP 1995, GNP 1997, GNP 1998, GNP 1999). At the West Enfield Dam, the median delay was 0.86 hours (range 0.3 to 49.7 hours) for hatchery smolts in 1993 (BPHA 1993b), and approximately 13 hours (range 0.2 to 102.9 hours) for wild smolts in 1994 (BPHA 1994).

While these delays can lead to direct mortality of Atlantic salmon from increased predation (Blackwell et al. 1998), migratory delays can also reduce overall physiological health or physiological preparedness for seawater entry and oceanic migration (Budy et al. 2002). Various researches have identified a “smolt window” or period of time in which smolts must reach estuarine waters or suffer irreversible effects (McCormick et al. 1999). Late migrants lose physiological smolt characteristics due to high water temperatures during spring migration (McCormick et al. 1999). Similarly, artificially induced delays in migration from dams, can result in a progressive misalignment of

physiological adaptation of smolts to seawater entry, smolt migration rates, and suitable environmental conditions and cues for migration. If so, then these delays may reduce smolt survival (McCormick et al. 1999).

Budy et al. (2002) found strong evidence that successive passage events over multiple dams in the Snake and Columbia River system lead to undetected Pacific salmon smolt mortalities, especially in the estuarine and near shore marine environments. Delays caused by long hydropower impoundments, and environmental conditions at project forebays, intakes, spillways, and downstream passage systems were hypothesized contribute to mortality of smolts after clearing the system. Such mortalities could occur as long as 6 or 7 weeks after a smolt has physically cleared the hydrosystem (Jensen et al. 1986). Barging around one or more dams, was shown to affect smolt development and long-term survival, by accelerating the net downstream progress and bypassing full exposure of smolts to ambient river conditions and other environmental cues during the passage window.

Downstream passage success of kelts was assessed as part of some of the radio tag studies conducted for smolts in the Penobscot (GNP 1989, Shepard 1989b, Hall and Shepard 1990b). Kelts tended to move downstream early in the spring (mostly mid-April through late May), regardless of whether fish were tagged in the spring or fall (i.e., most radio-tagged study fish generally stayed in the river near where they were placed until the following spring). Because kelt passage occurred during periods of spill at most dams, and a large portion of study fish used the spillage, success over main stem Penobscot River dams was usually greater than 90% at any one site. Kelt attraction to, and use of, downstream passage facilities was highly variable depending on facility, year of study, and hydrological conditions (e.g., spill or not). At the upstream confluences (i.e., the Stillwater Branch and the main stem), kelts followed the routes in approximate proportion to flow in the two channels.

Entrainment and Impingment

Dams equipped with hydroelectric generating facilities entrain and impinge downstream migrating Atlantic salmon. Entrainment occurs when downstream migrants pass through turbines and die or are injured by direct contact with turbine runners, shear forces, cavitation, turbulence, or pressure changes. Impingement occurs when a fish comes in contact with a screen, a trashrack, or debris at the intake. This causes bruising, descaling, and other injuries. Impingement, if prolonged, repeated, or occuring at high velocities also causes mortality. Entrainment mortality for salmonids ranges near 10-30% at hydroelectric dams depending upon fish length (juvenile vs. adult), turbine type, runner speed, and head (EPRI 1992). Passage through Francis turbines results in the greatest mortality (average 20%), followed by Kaplan (12%), and bulb turbines (9%) (Odea 1999). Passage through turbines can also lead to indirect mortality from increased predation and disease (Odea 1999). Where multiple dams exist, such as on the Penobscot River, the losses of downstream migrating smolts from turbine entrainment are often cumulative and biologically significant. Because of their larger size, with turbine mortality of kelts is expected to be significantly greater than 10 to 30% (FERC 1997).

Very few studies have been conducted in Maine to directly assess fish entrainment and mortality on Atlantic salmon at hydroelectric facilities. In the only known study addressing turbine-passage mortality at a Penobscot River hydropower dam, Shepard (1993) estimated acute mortality of hatchery smolt passing through the two horizontal Kaplan turbines at the West Enfield dam at 2.3% (n = approximately 410). Delayed mortality of the control group (smolts exposed to similar conditions except turbine passage) was quite high ranging from 20% in 1993 to 40% in 1992. Delayed mortality of turbine-passed smolts was considerably higher, ranging from 42% in 1993 to 77% in 1992. The high observed delayed mortality in the control group lead Shepard (1993) to conclude that any comparisons of delayed mortality between the control and treatment would be unreliable.

Studies conducted by the NMFS in 2003 reported a much higher rate of dead smolts in the Penobscot smolt traps (5.2%) compared to parallel studies on the Narraguagus (0.3%) (USASAC 2004). Although some of this difference could be due to the fact that most of the smolts in the Penobscot study were hatchery origin while all of the Narraguagus smolts were wild or naturally reared, the nature of injuries observed for the 22 Penobscot smolt mortalities indicated that more that 60% were the result of entrainment (USASAC 2004). Injuries attributed to turbine entrainment were also noted on smolts collected alive during the studies.

8.1.2.2.2 Road Crossings

Corrugated metal culverts are frequently installed at road crossings rather than bridges to reduce costs. Culverts and poorly designed bridges continue to sever habitat connectivity within the range of the GOM DPS. Bridges with hydraulic openings less than the natural stream width increase velocities that can delay or block fish passage. Improperly placed or designed culverts create barriers to fish passage through hanging outfalls, increased water velocities, or insufficient water velocity and depth within the culvert. Poorly placed and undersized culverts thus reduce access to potential habitat. Culverts can also degrade habitat quality through direct loss of habitat, upstream and downstream channel impacts including scour and deposition and loss of food production (Bates 2003). According to Gibson et al. (2005), culverts create more passage barriers to fish passage than other structures.

The extent of impacts on salmon populations from improperly installed or designed road crossings is not well known. In 2003 and 2004, fish passage at road crossings in Kenduskeag Stream and the Piscataquis River were evaluated using the Vermont Stream Geomorphic Assessment protocols (Baker 2004a). In the Kenduskeag River watershed, a total of 27 bridges and 22 culverts were evaluated for fish passage. Seven of the 22 culverts surveyed obstructed passage due to perched outlets or low flows. Of the 84 culverts evaluated in the Piscataquis River watershed 30% were physical barriers to fish passage (Baker 2004b). The cause of most perched or cascading outlets was undersized culverts. In both surveys, bridges seemed to be properly sized to provide passage for fish at most flows.

8.1.2.3 Natural Barriers

Natural geological falls occur in many of the rivers within the range of the GOM DPS and can act as temporary barriers or deterrents to fish passage during certain flow conditions. To facilitate fish passage at natural falls, fish passage improvements were built at Bad Little Falls on the Machias River in Machias (Fletcher et al. 1982) and at Saco Falls on the Pleasant River (Dube and Jordan 1982). Concrete deflectors were built to provide eddies and resting areas for salmon moving upstream through the gorge at Bad Little Falls. On the Pleasant River a Denil fish ladder was constructed at Saco Falls in 1955 to improve fish passage around this natural obstruction (Dube and Jordan 1982). The MASC installed a Denil fish ladder at Marino Falls in Cathance Stream to enhance upstream passage of Atlantic salmon in 1962.

Beaver dams are common on Maine rivers and are typically temporary partial obstructions (Havey and Fletcher 1956, Baker 2004a). They can temporarily alter habitat and block access to spawning habitat, thereby reducing salmon production. Atlantic salmon and beavers co-evolved; thus, a shifting mosaic of historically available tributaries for Atlantic salmon allowed both species to co-exist within a watershed with minimal interactions. First-order and smaller second-order streams are those most likely to have chronic beaver dam obstructions (Schlosser and Kallemeyn 2000), yet these streams are the least likely to be used by a significant portion of salmon run. Typically, spawning salmon use these smaller streams only in years with ample autumn flows and significant salmon runs. In third-order and smaller second-order streams, beaver dams can obstruct access or inundate spawning areas, and occasionally have significant local effects on salmon production. Small tributaries can quickly become inundated changing riffle-pool complexes, increasing stream depth, increasing water temperature, and changing sediment transport (Naiman et al. 1986, Naiman et al. 1988). Beaver dams can shift entire species assemblages in streams from cold-water to warm-water dominant communities (Naiman et al. 1988, Collen and Gibson 2000).

Generally, beaver dams do not limit upstream migration for adult Atlantic salmon in the main stem habitats. In years of low water conditions, beaver dams may prevent access to some spawning areas (ASA 1998); therefore, the MASC breaches beaver dams on important spawning streams each fall.

8.1.3 Degradation of Water Quality

Water quality in Maine's rivers and streams have improved significantly since passage of the Federal Water Pollution Control Act Amendments of 1972 (Clean Water Act). Historically, most major rivers systems in Maine including the Penobscot, Kennebec, and Androscoggin were heavily polluted. Diminished water quality continues to impact rivers within the range of the GOM DPS today; although, water quality is substantially better than was the case in the early and mid 1900s (Elson et al. 1973).

The Maine Department of Environmental Protection (DEP) operates the program that designates water quality classifications in Maine. The DEP has four water quality classifications for freshwater rivers and streams (Classes AA, A, B, and C), three classes

for marine and estuarine waters (Classes SA, SB, and SC), and one class for lakes and ponds (Class GPA).

Class AA rivers and streams are managed for their outstanding natural ecological, recreational, social, or scenic qualities. Discharges, dams, or other significant human disturbances are prohibited on Class AA waters. Class A waters are managed for high water quality and direct discharges of pollutants are highly restricted. Class B and C waters allow treated discharges, dams, and other human disturbances but, at a minimum, must attain the fishable/swimmable goals of the Clean Water Act, must be suitable for drinking water supply after treatment, and must maintain the structure and function of the biological community.

Within estuarine and marine waters, Class SA waters are managed for the highest water quality and no direct discharges of pollutants are allowed. Class SB and SC waters allow treated discharges but must be fishable/swimmable and maintain the structure and function of the biological community.

Class GPA lakes and ponds must be suitable for the drinking water after disinfection, recreation in and on the water, fishing, industrial process and cooling water supply, hydroelectric power generation and navigation and as habitat for fish and other aquatic life. The habitat shall be characterized as natural.

The classification of water bodies throughout the range of the GOM DPS is extremely variable. Most rivers in Downeast Maine are classified as either AA or A. Classifications of larger rivers including the Penobscot, Kennebec, and Androscoggin and some smaller rivers within the DPS can vary from AA to C. Even at the lowest classification of C, a waterbody presumably should be able to seasonally support Atlantic salmon. According to Title 38 §465 of Maine Revised Statutes, Class C waters in Maine must have dissolved oxygen levels of at least five parts per million or 60% of saturation, whichever is higher, except that in identified salmonid spawning areas where water quality is sufficient to ensure spawning, egg incubation and survival of early life stages, that water quality sufficient for these purposes must be maintained.

Some waters within the range of the GOM DPS do not currently attain their designated water quality standards. Under Section 303(d) of the Clean Water Act, states, territories, and tribes are required to develop lists of impaired waters that do not meet water quality standards. The law requires that these jurisdictions establish priority rankings for impaired waters on the lists and develop action plans including TMDLs (Total Maximum Daily Load) to improve water quality (MDEP 2004). Appendix 9 lists impaired waters within the range of the GOM DPS. Non-point source (NPS) pollution occurs in every river within the range of the GOM DPS. Sources of NPS pollution include agriculture, airborne pollutants (e.g., mercury deposition, acid rain, etc.), livestock grazing, septic systems, forestry, public and private roads, stream channel alteration, and urban runoff. Aside from mercury deposition, the most common NPS pollutants are sediment and nutrients. Other NPS pollutants include agricultural pesticides, heavy metals, pathogens (i.e., bacteria and viruses), and toxic chemicals. The prevailing land use patterns and

disturbances within a given watershed determine the type and amount of NPS pollution. While NPS pollution issues are noticeable in all rivers within the range of the GOM DPS, the cumulative effect on water quality is most evident in the Penobscot, Kennebec, Androscoggin, and Sheepscot Rivers. Urban and agricultural NPS sources have been identified in the Penobscot, Kennebec, and Androscoggin Rivers by entities including the Maine DEP, the PIN, and various county Soil and Water Conservation Districts. For example, the Piscataquis River frequently becomes very turbid having elevated levels of suspended solids after significant rainfall events or during snowmelt (Dan Kusnierz, Penobscot Indian Nation, personal communication).

Pollutants discharged from point sources also affect water quality within the range of the GOM DPS. Common point sources of pollutants include publicly operated waste treatment facilities, overboard discharges (OBD, a type of waste water treatment system), and industrial sites and discharges. The Maine DEP issues permits for licensed point source discharges. Conditions and license limits are set to maintain the existing water quality classification. Generally, the impacts of point source pollution are greater in the larger rivers of the GOM DPS.

The DEP has a schedule for preparing a number of TMDLs for rivers and streams within the Penobscot, Kennebec, and Androscoggin River watersheds. The main stem of the Penobscot River from its confluence with the Mattawamkeag River to Reeds Brook in Hampden has restricted fish consumption due to the presence of dioxin from industrial point sources. Combined sewer overflows from Milford, Old Town, Orono, Bangor, and Brewer produce elevated bacteria levels, thus inhibiting recreation uses of the river (primary contact). The lower area of the river south of Hampden to Verona Island is impaired due to contamination of mercury, PCBs, dioxin, and bacteria from industrial and municipal point sources. The West Branch of the Penobscot River is impaired due to hydro development and water withdrawals, thus creating aquatic life issues. Color-inducing discharges in the West Branch of the Penobscot River are affecting water quality in the Penobscot River. Many small tributaries on the lower river in the Bangor area have aquatic life problems due to bacteria from both NPS and urban point sources. Parts of the Piscataquis River (a major tributary of the Penobscot) and its tributaries are impaired from combined sewer overflows and dissolved oxygen issues from agricultural NPS and municipal point sources. Approximately 160 miles of the Penobscot River and its tributaries are listed as impaired by the DEP.

The Androscoggin River has restricted fish consumption due to the presence of dioxin. In addition, combined sewer overflows in the Androscoggin have increased the presence of bacteria in the lower river. Municipal and industrial point sources on the lower Androscoggin River have added nutrients and reduced the dissolved oxygen content and transparency of the water. Approximately 177 miles of the Androscoggin River and its tributaries are listed as impaired by the DEP.

The Kennebec River has restricted fish consumption due to the presence of dioxin from industrial point sources. Combined sewer overflows from Skowhegan to the Gardiner-Randolph region on the river produce elevated bacteria levels, thus inhibiting recreation

uses of the river (primary contact). The Sebasticook River (a tributary to the Kennebec) is contaminated with PCBs and other hazardous materials. Approximately 208 miles of the Kennebec River and tributaries are listed as impaired by the DEP.

8.1.3.1 Acid Rain and Acidified Water

The term "acid rain" is commonly used to mean the deposition of acidic components from air-born pollutants in precipitation and dry particles. Burning of fossil fuels in factories and cars is the predominant cause of acid rain. When fossil fuels are burned to produce energy, the sulfur that is present in the fuel combines with oxygen and becomes sulfur dioxide (SO_2); nitrogen released into the air becomes nitrogen oxide (Nox). Although the state of Maine produces the least amount of sulfur dioxide in New England, prevailing wind patterns and other factors have resulted in more acid rain damage to the eastern half of North America including Maine than the western half. In addition to these sources of sulfates, the factors that make Maine waters more susceptible to acidification include: natural organic acidity (DOC); dilution of base cations through increases in discharge; salt effect and anthropogenic sources of nitrates (Kahl et al. 1992).

The National Atmospheric Deposition Program (NADP) website lists mean Maine precipitation pH as 4.8 for the last two years (nadp.sws.uiuc.edu). Pre-industrial revolution precipitation pH has been estimated at 5.0 (EPA 2003), and in the last 15 to 20 years mean precipitation pH in Maine has increased from 4.6 to 4.8 (EPA 2003). Atlantic salmon populations cannot persist in chronically low pH environments. The physiological effects of chronically low pH on freshwater life stages of Atlantic salmon are well documented. Exposure to pH less than 4.5 causes rapid plasma ion loss and death, apparently from circulatory collapse. Alevins (sac fry) are the most susceptible life stage. This transitional life stage experiences high mortality even in healthy populations with high quality habitat. Chronic exposure to depressed pH results in reduced feeding and growth of juvenile Atlantic salmon (Haya et al. 1985). Fry growth declined and mortality increased at pH 5.5 compared to controls, with aluminum causing little increase in mortality above acid addition alone (Haines et al. 1990). Chronically low pH also results in altered behavior and gill damage (Jagoe and Haines 1990). Perhaps the most severe effect of low pH is the disruption of osmoregulatory ability, particularly after smolts enter seawater (Staurnes et al. 1993). Like alevins, the smolt stage is a life cycle bottleneck for stocks of Atlantic salmon, even healthy stocks experience high mortality during the transition to a marine environment.

Exposure to acid rain has been responsible for the decline and extirpation of Atlantic salmon populations from certain Norwegian and Canadian rivers (Watt 1981, Watt et al. 1983, Watt et al. 2000, Sandøy and Langåker 2001). In Nova Scotia, chronically depressed pH linked to anthroprogenic sources, specifically airborne sulfates and nitrates that originate largely from fossil fuel combustion, is the likely cause of salmon mortalities and population declines and losses (Watt et al. 1983, DFO 2000). In Norway and Nova Scotia, extirpation occurred in rivers with pH ranging from 4.2 to 5.3 (NMFS and FWS 2004).

In addition to chronic low pH levels, recent research has shown that pulses of low pH can impact some life stages of Atlantic salmon (Magee et al. 2003). Acidity levels of Maine's rivers vary in predictable geographic and seasonal patterns (Haines et al. 1990). Seasonally, the pH depression occurs during spring runoff when acidity stored in the snow pack is released into rivers and the greater volume of water dilutes the river's acid neutralizing capacity. This low pH pulse occurs as smolts are beginning to migrate and are altering their physiology in preparation for life in marine habitats and when alevins are preparing to emerge from the gravel as fry. Pulses of low pH occur in response to stormwater runoff (Staurnes et al. 1993), and in Maine declines associated with fall rains can be more severe than those in the spring (Johnson and Kahl 2005)

The effects of low pH are most severe in rivers that have a low buffering capacity, such as the granitic bedrock watersheds of Nova Scotia. By 1980, the mean annual pH in nine Nova Scotia rivers that historically contained salmon populations had dropped below 4.7 and as a result, the salmon were extirpated (Watt 1981). By 2000, natural reproducing Atlantic salmon were no longer present in many of the 65 rivers originating in the Southern Upland of Nova Scotia and were at reduced levels in all other rivers in the area. Populations in four rivers were entirely dependent on hatchery stocking (DFO 2000). Water quality and habitat modeling for 48 rivers suggested that only 8% of the rivers were capable of sustaining salmon populations at 10% marine survival (DFO 2000).

Rivers that are located east of the Penobscot generally have a lower acid neutralizing capacity (ANC) and pH than those located west of the Penobscot (Haines 1981, Haines et al. 1990, Johnson and Kahl 2005). This is due to the granitic bedrock underlying much of eastern Maine and the low ANC of the overlying soils. The lower ANC and higher DOC make the eastern sites more susceptible to event-driven pH depressions than sites to the west of the Penobscot River (Johnson and Kahl 2005). Within a given river system, minimum pH is typically lower in headwater streams and at higher elevations (Schofield 1981). This difference in range of pH within reaches is evident in the Narraguagus River, where pH measurements from 1990 through 1993 in tributaries such as Sinclair Brook were often below 5.0, while the main stem Narraguagus consistently remained above 5.0 (Beland et al. 1994). West Kerwin Brook, a tributary of the Machias River, also has lower pH relative to the main stem (Haines 1981).

Studies of eastern Maine coastal watersheds have shown that these rivers are becoming more dilute (i.e., fewer dissolved solids), with very little bicarbonate acid neutralizing capacity. Bicarbonate buffering will typically maintain pH 6-7 in receiving waters, while the depletion of bicarbonates can lead to pH levels below 5.0 in aquatic systems (Schofield 1981, Haines et al. 1990, Stoddard et al. 1999, Norton et al. 1999). Previously, it was believed that over time acid rain depleted the bicarbonate-based ANC of forest soils, shifting the buffering system to other chemical reactions (Schofield 1981, Haines et al. 1990). More recent evidence suggests that soil capacity to absorb sulfate and nitrate is the most important factor controlling acidity of surface waters, along with cation exchange and mineral weathering (Driscoll et al. 2001, Galloway 2001). The MAGIC Groundwater model (Denis et al. 2004) predicted that water chemistry in the selected Nova Scotia salmon streams remained relatively unchanged until the 1950s and

acid deposition had maximum effects on pH in the mid-1970s (Clair et al. 2004). The primary effects of acid deposition were a decrease in pH and an increase in base cations to surface waters, as the ion-exchange processes in soils released soil cations into surface waters.

Peat bogs are a common natural landscape feature in Maine, especially in the Downeast region. Waters draining peat bogs typically have lower pH due to naturally occurring organic acids produced in low oxygen environments associated with peat bogs. For example, in the Pleasant River pH is lower downstream of the Great Heath relative to upstream monitoring locations (Beland et al. 1994). This also occurs in the West Branch Narraguagus River where pH was found to be lower downstream of Denbo Heath than upstream of this peat bog (Beland et al. 1994). Johnson and Kahl (2005) detected a similar pattern on the Dennys River: the pH and ANC values for an upriver site were 7.26 and 124 µeq/L; while the same day just above head tide pH was 6.44 and ANC was104 µeq/L, due to naturally acidic tributaries draining wetlands between the two sites.

Historically, runoff from peat mining operations may have exacerbated naturally depressed pH in several Maine rivers. The only remaining peat mining operations within the eastern portion of the range of the GOM DPS is the Downeast Peat plant in Deblois (which is in the West Branch of the Narraguagus River), and in the Big Heath on the Chandler River. Recent improvements in state and federal licensing programs have greatly improved the water quality from drainage ditches in peat mining operations. In the 1980s peat mining for fuel pellets was proposed for several tributaries in the Penobscot River watershed partly in response to rising oil prices. It is possible that peat mining could again be considered economically viable in Maine.

Integrated crop management (ICM) programs for blueberries recommend that soil pH be maintained at 4.5 for weed control (the desired range is pH 4.3 to 4.8). If the soil pH is not already low, Maine Cooperative Extension recommends the addition of sulfur. If the soil is too acidic, growers are advised to use lime. Either of these practices can affect surface water pH. Some tributaries (e.g., Big Springy Brook in the Machias River drainage) have a springtime pH that is more acidic than rainfall. This suggests that soil acidity might also have a role in governing pH in streams. While the addition of sulfur to blueberry fields to lower soil pH is a standard Cooperative Extension recommendation, reportedly neither Cherryfield Foods or Jasper Wyman and Sons, Inc., the two largest wild blueberry growers in downeast Maine, engage in this practice (NMFS and FWS 2004). It is not known whether, or to what extent, small growers apply sulfur.

8.1.3.2 Acidified Water and Aluminum

Laboratory and field studies demonstrate that low pH leaches aluminum and potentially increases its toxicity to fish. Aluminum's solubility increases exponentially as pH declines below 7.0 (Haines 2001). The aqueous chemistry of aluminum is complex, the most toxic species are collectively termed labile forms. Labile forms include AlOH++, AlOH2+, AlF++, AlF 2+ and Al+++ (hereafter referred to as labile aluminum).

Dissolved organic carbon (DOC) readily binds with labile aluminum (as well as other metals) and these organic carbon/aluminum complexes are not toxic.

Osmoregulatory failure seems to be the most significant impact of acidified water and aluminum. This toxic effect is significant for developing alevins and migrating smolts, life stages that are undergoing significant physiological transitions and already experience high mortality.

The toxic effects of aluminum have been well studied in Norwegian salmon rivers. Salmon populations in 24 rivers were not affected by labile aluminum less than 8 ug/l, pH greater than 6.0 and at least 50 ueq/l of acid neutralizing capacity (Staurnes et al. 1995). Varying degrees of impact were observed in 26 Norwegian streams with intermediate pH (5.2 to 6.2), greater amounts of labile aluminum (10 to 60 ug/l), and acid neutralizing capacity between 20 and 40 ueq/l (Staurnes et al. 1995). Salmon were extirpated from 22 Norwegian rivers with pH less than 5.7, labile aluminum levels in excess of 20 ug/l and acid neutralizing capacity less than 10 ueq/l (Staurnes et al. 1995). Laboratory experiments using Norwegian salmon stocks showed that smolts experienced osmoregulatory failure and 60 to 75% mortality when exposed to freshwater conditions at pH 5.0 with 50ug labile aluminum and then subjected to a 24-hour seawater challenge (Staurnes et al. 1993, Rosseland et al. 2001, Kroglund et al. 2001).

In North America, Pauwels (1990) recorded a significant reduction of plasma chloride concentration but no mortality of smolts exposed for 11 days to pH 4.6-5.5 with 20-84 ug labile aluminum. About 4% mortality occurred on the 13th day with no additional mortality occurring until the 21st day. However, these fish were never challenged with seawater. Magee et al. (2001) documented altered behavior of migrating salmon smolts after exposure to constant low pH and elevated aluminum. This may affect smolt survival. Magee et al. (2001) also documented that the migratory behavior of salmon smolts in the Narraguagus River was similar to that of hatchery smolts exposed to acidified water in the study. Magee et al. (2001) found no mortality occurred after a 14 day exposure to stream water with pH declining from 6.0 to 5.1 and a short (<24 hr) acidic pulse to pH 4.5. In a separate study, there was substantial mortality when smolts, exposed to both a constant low pH and pulsed exposure, were then placed in seawater (Magee 1999, Magee et al. 2003). Saunders et al. (1983) reported ionoregulatory disruption within four weeks, and 24% mortality after 10 weeks between pH 4.2 and 4.7. Farmer et al. (1989) reported that pH 5.0 elicited no significant reduction in plasma osmolality, hematocrit, chloride concentration, branchial Na+/K+ ATPase activity, or mortality during a 112 day period in spring. Recent research indicates that naturally reared smolts in eastern Maine have low levels of sodium/potassium ATPase activity relative to Maine hatchery smolts and smolts from several New Brunswick and Newfoundland rivers (McCormick et al. 2002).

The mean pH of precipitation falling in Maine is about 4.8 (nadp.sws.uiuc.edu) and large amounts of aluminum are mobilized from Maine soils to aquatic environments. The synergistic effect of aluminum toxicity exacerbates the stress from acidity (Kroglund et al. 2001). Watersheds located east of Penobscot Bay are dilute with very little acid-

neutralizing capacity and low pH, which mobilizes toxic aluminum. The pH depressions that accompany spring and fall runoff may exacerbate this toxic effect.

8.1.3.3 Pesticide Use

Pesticides used for agricultural and other land use practices can include insecticides, fungicides and herbicides. Of these, insecticides are generally the most toxic to Atlantic salmon, followed by fungicides and herbicides (Maine TAC 2002). Improper applications of pesticides may introduce harmful toxins into receiving watersheds.

The use of pesticides may have direct or indirect adverse effects to Atlantic salmon or their habitats. Direct effects occur when Atlantic salmon and the chemical come in direct contact (Norris et al. 1991). Indirect effects result from chemically induced modification to habitat or non-target organisms (e.g., food sources). Pesticide effects on salmonids may range from acute (i.e., lethal), to chronic (i.e., sublethal). Effects on aquatic life depend primarily on the concentration and duration of exposure. Specific effects of pesticides on Atlantic salmon are influenced by factors such as concentration, toxicity, water quality (e.g., pH, temperature, conductivity, alkalinity), and stream flow velocity. Salmonid LC50s (lethal concentration to 50% of the individuals in a given time) are known for most of the pesticides used in Maine agriculture (Maine TAC 2002). However, the effects of mixtures of pesticides upon fish have not been adequately studied. All available data suggest that pesticide concentrations in Maine's salmon rivers are several orders of magnitude less than published thresholds for acute toxicity (Maine TAC 2002).

The effects of chronic or sublethal pesticide exposure to sensitive life stages of Atlantic salmon such as fry emergence and smoltification are not well understood. Sublethal concentrations of pesticides may impair behavior or physiological functions in fish (Trial 1986, Waring and Moore 2004). Moore and Waring (1996, 2001) documented the effect of several pesticides on Atlantic salmon olfactory capabilities. Scholz et al. (2000) documented that a common pesticide cab disrupt pacific salmon predator avoidance and homing behaviors.

<u>Agriculture</u>

Since the 1950s, the area of crop and pasture land in Maine has declined by about 900,000 acres (USDA 1999). Various crops including blueberries, hay, potatoes, corn, and oats are still cultivated however. Within the range of the GOM DPS, Androscoggin, Kennebec, and Washington counties are the leading producers of agriculture. Current agricultural practices in Maine, including the use of pesticides, continue to impact the DPS and its habitat. However, the effects of pesticide exposure to Atlantic salmon have not been fully investigated. Information pertaining to pesticide use and its effects on Atlantic salmon is best known for wild blueberry cultivation in Washington County. Wild blueberry production is the primary agricultural land use in the downeast watersheds. Approximately 60,000 acres of blueberry land is currently in production. Approximately 60 to 70% of this acreage is located in Washington County (Maine TAC 2002). Wild blueberry growers in Maine use a number of pesticides (brand or trade names in parentheses). Insecticides used include azinophos-methyl (Guthion, Sniper 2E), carbaryl

(Sevin), diazinon, malathion (Cythion), methoxychlor (Marlate) phosmet (Imidan), and Bacillus thuringiensis (BT)(Javeline, Biobit - BT is a bacterium). Herbicides used include fluazifo-p butyl (Fusilade), glyphosate (Roundup), hexazinone (Velpar), sethoxydim (Poast), terbacil (Sinbar) and 2,4-D ester. Fungicides used include propiconazole (Orbit), chlorothalonil (Bravo), benomyl (Benlate), captan and captec (Captan) and triflorine (Funginex; MASTF 1997). Most of these chemicals have not been routinely detected in historical water samples with the exception of hexazinone. DDT (banned since 1972 but its metabolites persist in the environment), phosmet, guthion, propiconazole and chlorothalonil have been detected intermittently at low concentrations. Increased monitoring would be required to accurately determine levels of pesticides and their transport mechanisms, fate, and toxicity.

The Maine Board of Pesticides Control (Maine BPC) has conducted most of the recent environmental monitoring of pesticides used on blueberry fields. In 1987, the Maine BPC conducted a drift study during an azinphos-methyl (brand or trade name: Guthion) aerial application. During the sprays, approximately 3% of the spray was estimated to have been deposited off-target (Jennings 1987). Most of the residues were close to the spray area and concentrations decreased with distance from the blueberry fields. Very small amounts of drift were found as far as 400 feet from the spray site.

From 1991 to 1994, the MASC and Maine BPC sampled and analyzed surface water from the Narraguagus, Pleasant, and Machias river drainages for pesticide residues. Samples were screened for all pesticides used in blueberry fields. Only hexazinone (Velpar) was routinely identified in the Narraguagus and Pleasant rivers, where it was found throughout the year (Magee 2000). Pesticide applications occur from May through June, but hexazinone has been detected in water samples year-round. No other pesticides in the analytical suite were detected. DDT and DDE were found in some samples in the Narraguagus River ranging from 12-314 ppb and 12-39 ppb, respectively (Magee 2000). In recent years, other pesticides detected in surface water from Washington County rivers include terbacil (Sinbar; Chizmas 2000), phosmet (Imidan; Chizmas 2001), triforine (Beland et al. 1995), azinphos-methyl (Guthion; Magee 2000), and benomyl (Benlate; Magee 2000).

In 1997, the Maine BPC began a survey of seven salmon rivers in the downeast region of Maine. Of 33 different pesticides tested in surface water samples, only hexazinone was detected in the rivers. Hexazinone was found in 19 of the 64 samples taken, and was only found in the Narraguagus, Pleasant, and Machias Rivers. Concentrations in these three rivers ranged from 0.1-1.7 ppb (Chizmas 1999). In 1999, the Maine BPC conducted another study of drift during aerial pesticide applications. Hexazinone (maximum concentration 3.8 ppb) was found in 11 of 13 samples taken from the Narraguagus and Pleasant Rivers. Terbacil (Sinbar) was also detected at 0.148 ppb.

In the 2000 field season, the Maine BPC continued their investigation of pesticide drift. Both hexazinone and phosmet were found in off-target areas on drift cards. Water samples were also analyzed in the study. Hexazinone was found in most water samples taken near blueberry barrens. Phosmet was found in three agricultural ponds that are

tributaries to the Narraguagus and Pleasant River. The ponds are located immediately adjacent to blueberry fields and are used seasonally as sources of irrigation water. The ponds overflow in the spring, but not in the summer. Phosmet concentrations in pond surface water ranged from 0.08 to 0.52 ppb (Chizmas 2001).

In 2001, pesticide drift during spray operations was examined by the Maine BPC at three locations on the Narraguagus River and four locations on the Pleasant River (Chizmas 2002). In addition to drift cards, an automated water sampler (Iscos®) was used to collect a time-series of surface water samples during spray events. Drift during propiconazole and phosmet applications was detected on filter cards, but not in water samples on the Narraguagus River. In the Pleasant River, chlorothalonil (0.103 - 0.79 ppb) and phosmet (0.155 to 3.76 ppb) were detected in water samples and drift cards. Hexazinone was detected in water samples at two Narraguagus River locations (0.084 to 1.22 ppb) and at three Pleasant River locations (0.41 to 2.45 ppb).

The Maine BPC continued its drift studies associated with spray applications in 2003 and placed an automated water sampler and drift cards at eight locations on the Narraguagus (n=2) and Pleasant Rivers (n=6). Phosmet was found on drift cards at one location on the Narraguagus River, and in water (0.28 to 1.95 ppb) and on drift cards from Montegail Pond, a waterbody that discharges to the Pleasant River. Pesticide drift was detected 1,500 feet from one of the spray sites (Jackson 2003).

As noted, hexazinone has been detected at numerous sites in trace amounts in the Narraguagus, Pleasant, and Machias Rivers (Beland et al. 1995, Chizmas 1999, Chizmas 2000, Chizmas 2002, Maine TAC 2002). The pervasive presence of hexazinone in surface water sampled at low flow periods suggests that the material is entering the river through groundwater flow rather than storm runoff (Beland et al. 1993). Although hexazinone has been detected in surface water samples in the range of 4 to 9 ppb, concentrations are typically less than one ppb. Some groundwater samples have hexazinone levels approaching 30 ppb. Groundwater does not appear to be an important pathway for other pesticides (Maine TAC 2002).

Monitoring the presence of pesticides in aquatic habitats is complicated by the fact that several compounds (e.g., organophosphate pesticides), are very short-lived in the environment or are not very water-soluble (hexazinone is an exception) and are thus difficult to detect in water or fish tissue. Pesticides can adsorb to soils and be transported to watercourses during storm events. Sediment analyses are one possible means to detect pesticide residues. However, recent analyses of sediments collected above and below areas of blueberry cultivation in the Narraguagus River did not detect any pesticide residues (Spaulding 2005). Pesticide concentrations in sediments of the other rivers have not been determined.

Forestry

About 90% of the land in Maine is in forests and commercial forestry is a major land use throughout the range of the GOM DPS (USDA 1999). Historically, pesticides have been used in commercial forestry to control insect outbreaks such as the spruce budworm.

Currently, the biological agent *Bacillus thuringiensis* (also referred to as Bt) is a registered pesticide in Maine used to control outbreaks of defoliating insects. These agents are specific to target organisms (e.g., moth larvae). Herbicides such as Triclopyr (Garlon) and glyphosate (Accord) are occasionally used to control post-harvest hardwood growth, promote softwood regeneration, and to prepare sites for planting. Generally, herbicides are used on one site for no more than a year or two, no more than one spray a year. Since the harvest frequency is about 35 to 40 years for pulpwood and 80 years for saw logs, the spray frequency is usually no more than twice in that period. During herbicide applications, there is the potential for these chemical compounds to enter streams through runoff and drift (Norris et al. 1991). A large number of chemical compounds used as pesticides have been shown to have endocrine disrupting activity on Atlantic salmon and their habitats as discussed in Section 8.1.1.7 below.

Road Maintenance

The maintenance of road rights-of-way in Maine includes herbicide spraying for brush control. In the past few years, sprays have not been used in Washington and Hancock Counties (Maine Department of Transportation, Division 2) due to concerns about the health of Atlantic salmon (Maine TAC 2002). Outside of Washington and Hancock Counties, a 50/50 mix of triclopyr (Garlon) and tricamba (Vanquish) are used in most roadside spray applications. No-spray buffers of 100 feet are maintained along the Sheepscot and Ducktrap Rivers and Cove Brook, as well as within 50 feet of other surface waters. Herbicide sprays are not applied during spring, on standing water or bedrock. All road maintenance crews receive training in Maine DOT's spray protocols. Due to the relatively low toxicity of herbicides and the low application rate, roadside maintenance is not thought to significantly impact Atlantic salmon or its habitat in Maine (Maine TAC 2002).

Other Contaminants

In addition to the pesticides discussed above, Atlantic salmon and their habitat may be affected by a suite of other environmental contaminants including organochlorine compounds (e.g., DDT and its metabolites, polychlorinated biphenyls [PCBs], polychlorinated dibenzo-p-dioxins, and polychlorinated dibenzofurans), trace elements (e.g., mercury), and other chlorines (e.g., calcium hypochlorite).

All waters in Maine are listed by the DEP as having elevated mercury presumed to be from atmospheric contamination and deposition. These contaminants are taken up by fish through diet or water. Chronic dietary exposure to elevated levels of mercury causes pathological injuries to Atlantic salmon parr including oxidative stress and brain lesions (Berntssen et al. 2003). In other fish species, mercury exposure affected predator avoidance (Webber and Haines 2003).

The class of chemical compounds known as organochlorines (or chlorinated organics) is composed of hundreds of chemicals, many of which are structurally complex, and all of which have at least one chlorine atom and one "benzene ring" (C_6H_6). Many organochlorines of industrial origin have yet to be fully identified or chemically speciated. The most widely recognized and studied contaminant groups within this class

are dioxins, furans, and polychlorinated biphenyls (Maine TAC 2002). Organochlorines tend to persist in the environment.

Dioxins, furans, and PCBs cause sublethal and lethal physiological effects in exposed fish through direct/acute toxicity to the exposed organism, chronic bioaccumulation in fatty tissue, and maternal transfer to eggs of exposed gravid females (Maine TAC 2002). Salmonids exposed by one or more of these routes experience loss of visual and motor function (Carvalho and Tillitt 2004); reduced adult and fry survival (Giesy et al. 2002); decreased total length and cranial length (Carvalho et al. 2004); general physiological and endocrine dysfunction; decreased egg viability and fry survival (Walker and Peterson 1994, Zabel et al. 1995); abnormal gene expression, genetic fragmentation (genotoxicity); and, in extreme cases, direct mortality (Sijm and Opperhuizen 1996).

A variety of natural processes, such as forest fires, can generate small amounts of a few of these compounds (e.g., dioxins) that can end up in surface waters. Surface waters may also receive dioxins and dioxin-like compounds through atmospheric deposition and trace discharges from municipal sewage treatment plants (Maine TAC 2002). Other sources of these compounds within the geographic range of the GOM DPS include landfill and hazardous waste disposal sites (e.g., the Eastern Surplus Superfund site on the Dennys River), bulk fuel storage facilities, pulp and paper mills, and other industrial operations that discharge into the river systems.

The indirect effects of chlorine compounds on salmon olfactory senses and homing behavior are currently unknown (Maine TAC 2002). A number of studies have documented sublethal effects of total residual chlorine (TRC) in effluent on fish (Post 1987, Buckley 1976). Reductions of hemoglobin and hemocrit levels indicative of anemia occur as TRC levels approach approximately 0.03 mg/L.

Chlorines are typically used in Maine to disinfect wastewater prior to discharging into waterbodies. DEP rules require concentrations of chlorines in wastewater to be at levels not directly harmful to fish species including Atlantic salmon. Chlorines are also discharged into rivers and streams via overboard discharges (OBD). An OBD is an alternative wastewater treatment system for sites where municipal sewer connection is not possible and where a traditional septic system is not feasible. The simplest kind of OBD is a holding tank with a chlorinator for the overflow pipe (Maine TAC 2002). OBDs use chlorine tablets (calcium hypochlorite) in the chlorinator unit. There are approximately 1,688 licensed residential or commercial OBDs in Maine. Many of these are located within the range of the GOM DPS.

Since 1987, the construction of new OBDs has been prohibited in Maine. In 1990, the Maine OBD program was initiated by the State legislature (38 MRSA Section 411-A) to help fund replacement systems that would eliminate OBDs in certain areas. Currently, the focus of the replacement program is in shellfish areas that would be open to shellfishing if the OBDs were removed. Maine DEP is responsible for annually inspecting all OBD systems and generating a priority list for replacement. In addition to the Maine DEP, the Farmers Home Administration and the Maine State Housing

Authority can provide grants or low interest loans to towns or community groups for replacement of OBDs.

Many of these contaminants are endocrine disrupters. The effects can occur in many life stages, and are often delayed in expression. A large number of chemical compounds have been found to have endocrine disrupting activity, including herbicides (2,4-D, atrazine), fungicides (benomyl, zineb), insecticides (DDT, methoxychlor, synthetic pyrethoids), industrial chemicals (dioxin, PCB, nonylphenols, phthalates), and trace metals (cadmium, lead, mercury). Numerous endocrine disrupters have been found in a variety of media (fish, sediments, mussels, etc.) throughout the range of the GOM DPS (MDEP 1999).

Endocrine disrupters are believed to affect smoltification in Atlantic salmon by disrupting hormone systems that facilitate the physiological processes necessary for seawater adaptation (Fairchild et al. 1999). In New Brunswick, Fairchild et al. (1999) documented a decline in returning adult Atlantic salmon in areas where the insecticide Matacil 1.8D had been sprayed to control an outbreak of spruce budworm during the time of smolt out-migration. Spruce budworm outbreaks are cyclical over 40 to 80 year periods and are not expected in the next 10 to 20 years. The particular pesticide used was not an endocrine disrupting compound, but the formulation included a known endocrine disruptor (4-nonylphenol) as an emulsifying agent. Exposure to 4-nonylphenol induced vitellogenin (an egg yolk protein) in Atlantic salmon smolts in the same manner as exposure to 17 β-estradiol (Sherry et al. 2001). Moore and Lower (2001) showed that exposure to atrazine (a triazine herbicide) and pentabromodiphenyl ether (a brominated fire retardant) reduced gill Na+/K+ ATPase activity, caused osmoregulatory disruption and elevated cortisol levels, reduced survival in sea water, and reduced migratory activity. These are the same effects reported by Magee et al. (2001) for Narraguagus River smolts.

Endocrine disrupting organochlorine compounds, including dioxin, PCBs, and DDT metabolites have been detected in Maine Atlantic salmon rivers (all fish tissue values following are expressed in wet weight). In the Pleasant River, DDT metabolites (8.1 to 11.2 ppb) and PCBs (5.3 to 8.6 ppb) have been found in brook trout and white suckers (DEP 1999). DDE (3 to 5 ppb) has been detected in white suckers from the Narraguagus River, Pleasant River, and Cove Brook (USFWS 2005 unpublished data). PCBs have been found in smallmouth bass (91 to 168 ppb), white suckers (52 to 54 ppb), and sediments from the Dennys River, downstream from the Eastern Surplus Superfund Site (Mierzykowski and Carr 1998, EPA 2005 unpublished data) and in smallmouth bass (23 ppb) and white suckers (12 ppb) from the East Machias River (Mierzykowski and Carr 1998). Higher levels of many of these compounds have been found in the Penobscot and Kennebec watersheds (DEP 2004).

In a recent study at the University of Maine, endocrine disruption was not exhibited in Atlantic salmon pre-smolts exposed to several pesticides (Spaulding 2005). Pre-smolts were exposed to mixtures of hexazinone, propiconazole, 2,4-D, terbacil, and phosmet in five weekly, 24-hour tests. The exposures did not affect smoltification, mortality

following saltwater challenge tests, body length or weight, hematocrit levels, or plasma steroid concentrations.

The E-SCREEN bioassay (Soto et al. 1995) has been used to demonstrate that several pesticide active ingredients used in blueberry operations exhibited estrogenic activity of 50 to 75% of 17β estradiol, and several commercial formulations had activities of 25% or greater (Van Beneden and Morrill 2002, Haines and Van Beneden 2003). Among these pesticides, 2,4-D, propiconazole, methoyclor, phosmet, and hexazinone exhibited the activity of a xenoestrogen (a foreign substance that may act like estrogen).

The Maine TAC (2002) concluded that there are not sufficient water quality data to determine the extent of exposure of Atlantic salmon to endocrine disrupting chemicals in the eastern portion of the GOM DPS. A similar analysis for large rivers within the range of the GOM DPS has not yet been conducted. Thus, existing data are not sufficient predict the potential effects of endocrine disruptors on salmon restoration (Maine TAC 2002).

8.1.3.4 Nutrient Cycles

Surface waters in Maine are naturally oligotrophic because the primary parent material is often granite. Furthermore, small to moderate size rivers are heavily dependent upon allochthonous nutrients and energy (Vannote et al. 1980). Changes in the diadromous fish communities and land use have likely altered the ambient nutrient cycles substantially in most rivers in Maine. Historically, anadromous fish provided substantial nutrient subsidies to many rivers (see Section 3). Those nutrients would have arrived in one or only a few events each year (e.g., the alewife run); thus, large portions of the overall nutrient budget would have historically been received in just a few weeks in the spring time while water temperatures were still low. In a given reach, much of the nutrient uptake (e.g., carcass consumption) would have occurred relatively quickly with the remainder of nutrients being carried away to downstream reaches also relatively quickly given the high flows common in the spring.

Today, few rivers host the full complement of diadromous fish due primarily to inadequate fish passage facilities at dams. Land uses such as road building and agriculture also provide a steady flow of allochthonous nutrients into many rivers (Allan 1995). However, the timing and composition of these anthropogenic nutrients is likely quite different compared to that which existed historically. Nutrient enrichment from surface runoff can occur well into summer months when water temperatures are warmer. This can increase growth of aquatic vegetation and decomposition which may cause dissolved oxygen levels to fall below levels optimal for Atlantic salmon growth. In addition, the P:N ratio may also be very different than it was historically. Thus, the nutrient cycles in many rivers have likely changed, especially with respect to composition and timing. The direct implications for Atlantic salmon growth and survival remain largely unknown (USASAC 2006).

8.1.4 Alteration of Water Temperatures

Water temperature partially delineates the geographical range of the Atlantic salmon (USFWS 1983). Atlantic salmon require cool temperatures at all stages of their life history. The optimal temperature range for juvenile salmon feeding and growth in streams is 15 to 19ºC and the maximum limit for feeding is 22.5ºC (Table 8.2; DeCola 1970, Elson 1975, Danie et al. 1984, Elliott 1991). Increased water temperatures can also reduce dissolved oxygen levels in aquatic environments. Dissolved oxygen levels below 6 mg/l are not suitable for salmonids (Maine TAC 2002). Water temperature above 23ºC inhibits spawning migrations (Elson 1969, DeCola 1970, Danie et al. 1984, Hawkins 1989, Shepard 1995). Juvenile salmon can survive for several days at temperatures of 26 to 27ºC (Garside 1973, Elliott 1991). However, adult salmon mortalities have often been observed at temperatures of 26 to 27ºC (Garside 1973, Elliott 1991).

Table 8.1.4. Atlantic salmon temperature (ºC) requirements for freshwater life stages. Data are from published studies on Atlantic salmon, including experimental data and in situ measurements over the range of the species (North America and Europe).

Life Stage	Optimum Range	Min.[1]	Max.	References
Spawning	5-8	4.4	10	DeCola '70; Danie et al. '84; McLaughlin and Knight '87
Incubation	4-7.2	0.5	12	DeCola '70; Gunnes '79; Danie et al. '84; McLaughlin and Knight '87
Early Fry	8-19	0.5	23.5	Danie et al. '84; Jensen et al. '91
Juveniles				
Feeding	15-19	3.8	22.5 [2]	DeCola '70; Elson '75; Danie et al. '84; Elliott '91
Survival	0.5-20	0	29.0 [3]	Garside '73; Elliott '91
River Migration				
Smolt	7-14.3	5	19	LaBar et al. '78; Ruggles '80; Jonsson and Rudd-Hansen '85; Duston et al. '91; Shepard '91c
Adult	14-20	8	23 [4]	Elson '69; DeCola '70; Danie et al. '84; Hawkins '89; Shepard '95

Notes:

1. Minimum water temperatures reflect the requirements of southern populations and include winter temperature requirements. Northern populations have lower minima for some life stages (not included).
2. Highest temperature for feeding after acclimation at 20.0ºC.
3. Highest temperature for 1000 minute survival after acclimation at 25.0-27.0ºC.
4. Highest temperature for normal upstream migration. The lethal temperature for adult salmon is approximately 27.0ºC, depending upon acclimation and duration of exposure.

Maine is near the southern extent of the Atlantic salmon's range in North America. Therefore, the GOM DPS is vulnerable to elevated water temperature regimes (Maine TAC 2002). Depending upon annual variations in streamflow and ambient air temperatures, it is likely that reaches of many rivers experience summer water temperatures outside the preferred range of Atlantic salmon. Anthropogenic factors that likely contribute to elevated water temperatures include improper or unregulated land use practices, impounded reaches, industrial processing or cooling water discharge, low flows that increase net insolation (exposure to sun), and broad climatic changes (Maine TAC 2002).

Prior to the implementation of current forestry regulations and best management practices, forestry operations were likely the greatest cause of changes to thermal regimes in salmon rivers. Alteration of water temperature regimes is considered one of the most significant impacts from forest practices (Murphy and Meehan 1991). Solar radiation and increased air temperatures due to the removal of stream-side vegetation can also increase water temperatures. The effects of forestry have been substantially reduced by current regulations and management practices.

Dams inundate free-flowing reaches of river and increase stream temperatures upstream and downstream of the structure. Dam impoundments increase the water residency time within a given river reach, increase water depth, and reduce the daily fluctuations in water temperatures (FERC 1997). On rivers such as the Penobscot, Kennebec, and Androscoggin Rivers where multiple dams and industrial discharges exist, the thermal warming in Atlantic salmon habitat is cumulative and significant. Data collected by the PIN during the summer of 1993 showed an increase of 0.5ºC in water temperature over two impoundments in the lower Penobscot River (FERC 1997). Since 1987, MASC biologists have observed 92 dead Atlantic salmon on the trash racks at the upriver side of the Veazie Dam on the Penobscot River while performing daily trap tending operations, including 19 salmon in 2005. Observations of dead salmon on the trash racks often coincided with warm river temperature during week preceding the observation. In most instances, the average weekly temperature was 23°C or greater during the preceding week. Not all salmon dying in an impoundment reach the trash racks of the impounding dam. Shepard (1995) reported finding approximately 70 adult salmon mortalities during searches of the Veazie impoundment in 1988. Additional mortalities were also found above the Great Works Dam. These fish were found in a four-day period when the river temperature approached or exceeded 27°C each day. Shepard and Hall (1991) noted that similar numbers of dead salmon were observed in the lower river again in 1989 and 1990, occurring primarily during extended periods (i.e., several days) with water temperatures at or above 27°C.

Elevated water temperatures are also likely affecting Atlantic salmon and their habitat in smaller rivers. As discussed in Section 8.1.1.1, many small dams persist on practically every historical Atlantic salmon river within the range of the GOM DPS. These small dams may be increasing ambient water temperatures. In addition, blueberry processing plants may locally alter thermal regimes (MASTF1997). Processing plants are allowed to discharge 627,000 gallons of agricultural process water into the Narraguagus River per day (0.97 cfs). Up to 100,000 gallons per day (0.15 cfs) is allowed to attain a discharge temperature of 26°C. A permit allows up to 70,000 gallons per day (0.11 cfs) of agricultural process water discharge into the Machias River with a maximum temperature of 32°C, a temperature lethal to both juveniles (smolts) and adult salmon. In addition to lethal effects, areas of elevated water temperature may adversely affect salmon by acting as a thermal barrier to passage thereby inhibiting migration.

Finally, global climate change may also affect thermal regimes within the range of the GOM DPS. The global average surface temperature increased approximately 0.6°C during the 20th century (IPCC 2001). Within the range of the GOM DPS, spring runoff

has become earlier, water content in snow pack for March and April has decreased, and the duration of river ice has become shorter (Dudley and Hodgkins 2002). Thermal changes of just a few degrees Celsius can substantially alter protein metabolism (McCarthy and Houlihan 1997, Somero and Hofmann 1997, Reid et al. 1998), response to aquatic contaminants (Reid et al. 1997), reproductive performance (Van Der Kraak and Pankhurst 1997), smolt development (McCormick et al. 1997), species distribution limits (Keleher and Rahel 1996, McCarthy and Houlihan 1997, Welch et al. 1998), and community structure of fish populations (Schindler 2001). For Atlantic salmon specifically, Juanes et al. (2004) suggest that observed changes in adult run timing may be a response to global climate change. While some physiological changes at the individual level are quite predictable when changes in temperature are known, the interactions between individuals, populations, and species are impossible to predict at this time. The NRC (2004) concluded that some degree of climate warming or change in hydrologic regime could be tolerated if other problems affecting Atlantic salmon in Maine are reduced.

8.2 Overutilization for Commercial, Recreational, Scientific, or Educational Purposes

8.2.1 Commercial Fisheries

Commercial fisheries for Atlantic salmon have been both in nearshore areas using nets and weirs and in offshore waters outside of the U.S. Exclusive Economic Zone (EEZ). Most directed fisheries for Atlantic salmon have ceased. However, the impacts from past fisheries are important in explaining the present low abundance of the GOM DPS.

8.2.1.1 Nearshore Fisheries

The most complete records of domestic commercial harvesting of Atlantic salmon in the U.S. are for the Penobscot River. The trends and practices seen in the Penobscot fishery are likely indicative of what occurred in other rivers in Maine. Historical records also mention commercial salmon fisheries in the Dennys (Beland et al. 1982, NEFMC 1987), Androscoggin (Beland 1984) and Kennebec (Kendall 1935), among others, but data on location, time and volume of catch are not available. Stolte (1981) reported that nearly 200 pound nets were operating in Penobscot Bay in 1872. A record commercial catch of 200,000 pounds of salmon was recorded for the Penobscot River in 1888. By 1898, it had been reduced to 53,000 pounds. The directed commercial fishery was eliminated following the creation of the Atlantic Sea Run Salmon Commission (ASRSC) in 1948. The commercial harvest in the Penobscot that year was reduced to only 40 fish, weighing a total of 400 pounds.

Directed fisheries for Atlantic salmon in U.S. territorial water were further regulated by the adoption of the Atlantic salmon fishery management plan (FMP) in 1987 (NEFMC 1987). The FMP prohibits possession of Atlantic salmon in the U.S. exclusive economic zone (EEZ). Directed fishing for other species does, however, have the potential to intercept salmon as by-catch. Beland (1984) reported that fewer than 100 salmon per

year were caught incidental to other commercial fisheries in the coastal waters of Maine. Recent investigations also suggest that by-catch of Atlantic salmon in herring fisheries is not a significant mortality source for U.S. stocks of salmon (ICES 2004a). However, fishery observer coverage is currently being enhanced in order to refine mortality estimates.

Commercial fisheries for white sucker, alewife, and American eel conducted in state waters also have the potential to incidentally catch Atlantic salmon. In 1998, regulations were passed that set a maximum length of fyke nets used in the elver fishery and prohibited fyke nets from the middle third of any waterway to provide a zone of safe passage for migratory fish. MDMR staff fishing elver fyke nets with the required finfish excluder panel caught no Atlantic salmon during 1998. Alewife fisheries exist in many rivers. These fisheries are usually managed by the cities and towns in which they are conducted with some oversight from the MDMR. To date, there has not been a comprehensive analysis of the effects of alewife fisheries on Atlantic salmon populations.

8.2.1.2 Offshore Fisheries

The West Greenland fishery is one of the last directed Atlantic salmon commercial fisheries in the Northwest Atlantic. In August 2002, a multi-year conservation agreement with an annual termination date (available to both parties) was established between the North Atlantic Salmon Fund (NASF) and the Organization of Hunters and Fishermen in Greenland (KNAPK) which effectively bought out the commercial fishery for Atlantic salmon for a five year period. The internal-use fishery is not included in the agreement. From 2002 to 2005, the internal-use fishery harvested between 19 and 25 metric tons (mt; reported and unreported catch) annually. This fishery is a mixed stock fishery, catching both North American and European fish. The North American component of this mixed stock includes both Canadian and United States salmon. Maine-origin salmon are taken in low numbers by this fishery. Genetic analysis performed on samples obtained from the 2002 to 2004 fisheries estimated the North American contribution at 64-73% with the U.S.contributing between 0.1 and 0.8% of the total. The 90% confidence interval for the U.S. estimates are 0 to 141 salmon in 2002, 5 to 132 salmon in 2003, and 0 to 64 salmon in 2004 (ICES 2006). It is estimated that greater than 80% of the U.S.contribution is of Maine-origin salmon. Based upon historic tag returns, the commercial fisheries of Newfoundland and Labrador historically intercepted far greater number of Maine-origin salmon than the West Greenland fishery (Baum 1997).

A small commercial fishery occurs off St. Pierre et Miquelon, a French territory south of Newfoundland. Historically, the fishery was very limited (2 to 3 mt per year). There is great interest by the U.S. and Canada in sampling this catch to gain more information on stock composition. In recent years there has been a reported small increase in the number of fishermen participating in this fishery. A small sampling program was initiated in 2003 to obtain biological data and samples from the catch. Genetic analysis on 134 samples collected in 2004 indicated that all samples originated from North American salmon and approximately 1.9% were of U.S. origin. The 90% confidence interval around this estimate was 0-77 salmon (ICES 2006). Efforts through the North Atlantic Salmon Conservation Organization (NASCO) to continue and increase the scope and

nature of this sampling program are ongoing. These data are essential to estimate the potential threat this fishery may pose to the GOM DPS.

8.2.2 Recreational Fisheries

Sport fishing for Atlantic salmon in rivers in Maine dates back to the mid 1800s. By the late 1800s, recreational fishing for Atlantic salmon was common in Narraguagus, Penobscot, Pleasant, Machias, and East Machias Rivers (Baum 1997). The Dennys River has the reputation of being the only Maine river where angling for Atlantic salmon preceded the erection of impassable dams (Beland et al. 1982). Kendall (1935) cites *Forest and Stream Sportsman's Journal*, which reported that recreational catch for Atlantic salmon on the Penobscot River dropped in 1889 due to chemicals in the water from pulp mills, dams, and excessive netting downstream from Bangor. Restoration programs began to produce returns to the Penobscot River in the 1970s that attracted anglers. In part to build a constituency for the restoration program and because wild runs seemed robust, harvest regulations were not very restrictive through the 1970s. However, as the 1980s progressed and runs decreased, the ASRSC imposed increasingly restrictive regulations on the recreational harvesting of Atlantic salmon in Maine (Table 8.2.2.1). The allowable annual harvest per angler for these rivers was reduced from 10 salmon in the 1980s to 1 grilse in 1994. Angling was closed on the Pleasant River from 1986 to 1989. In 1990, a catch and release fishery was allowed on the Pleasant River. In 1995, regulations were promulgated for catch and release fishing for sea run Atlantic salmon throughout the other Maine salmon rivers, closing the last remaining recreational harvest opportunities for sea run Atlantic salmon in the U.S. In 2000, all directed recreational fisheries for sea run Atlantic salmon in Maine were closed.

Historically, Atlantic salmon sport anglers practiced very little catch and release primarily because catch rates are typically low. One exception would have been that 2SW fish were preferred and 1SW fish were more likely to be released. Further, 1SW return later in the season when effort was lower, thus exploitation was low (Baum 1989). Exploitation has been calculated for rivers where angler harvest and spawner returns were documented [exploitation = harvest/(harvest + spawner returns)]. Average annual exploitation rate for 2SW salmon in Maine rivers was estimated to be approximately 20% of the run (Beland 1984), and ranged from 15% to 35% (Beland 1987). Exploitation rates on returning Atlantic salmon ranged from 9.6% to 36.8% of the annual run in the Narraguagus River from 1962 to 1974 and 14% to 25% of the annual run in the Machias River from 1960 to 1974 (Beland 1987). Baum (1988) estimated exploitation in six Maine rivers based on redd counts for the years 1985 to 1987. For these years, harvest was from 8 to 15% of the combined spawning escapement for the Dennys, East Machias, Machias, Narraguagus, Sheepscot, and Ducktrap Rivers.

Table 8.2.2.1. Angling regulations for Atlantic salmon in Maine from 1979 to 2000, excluding the Pleasant River which was closed to directed angling from 1986 to 1989 and limited to catch and release beginning in 1990.

	Bag Limit		
Year	**Daily**	**Season**	**Special Regulations**
1979	2	None	None
1980	1	None	None
1981	1	None	None
1982	1	None	None
1983	1	10	Tag
1984	1	None	None
1985	1	5/season w/ 1 MSW	Tag
1986	1	5/season w/ 1 MSW	Tag
1987	1	5/season w/ 1 MSW	Registration > 25"
1988	1	5/season w/ 1 MSW	Registration > 25"
1989	1	5/season w/ 1 MSW	Registration of all
1990	1	5/season w/ 1 MSW	Registration of all
1991	1	5/season w/ 1 MSW	Registration of all
1992	1	1/season	Registration of all
1993	1	1/season	Registration of all
1994	1	1/season, grilse only	Registration of all
1995	1	1/season, grilse only	Registration of all
1996	0	C & R	None
1997	0	C & R	None
1998	0	C & R	None
1999	0	C & R	None
2000	Directed Angling for Atlantic salmon closed statewide		

On the Penobscot River mean annual exploitation rates (1971 to 1989) for wild and hatchery 2SW salmon ranged from 9.5% to 18.0% (Baum 1990), with exploitation of wild fish being highest, primarily because wild fish arrive early in the run when angler effort was highest. On the Penobscot River, exploitation rates decline in response to restrictive regulations, averaging approximately 24% from 1970 to 1984 and 11% from 1985 to 1988 (Baum 1989). Seasonal catch rates [(harvest + release)/(harvest + spawner returns)] calculated for the Penobscot River from 1979 to 1995 were highest for the months of May and June, compared to the two other two-month periods in the angling season (Trial 2005; Table 8.2.2.2). These catch rates did not decline with declining population size (Figure 8.2.2.1).

Table 8.2.2.2. Atlantic salmon catches from the Penobscot River below Veazie, 1979 to 1999 with numbers of fish kept (K) and released (R) by month. (Monthly data not available 1996 to 1999).

Year	May		June		July		Aug		Sept		Oct*		Total	
	K	R	K	R	K	R	K	R	K	R	K	R	Kept	Rel
1979	17	0	107	0	12	0	0[a]	0[a]	[a]	[a]	[a]	[a]	136	0
1980	216	11	427	39	72	11	10	6	6	25	5	13	736	105
1981	293	5	300	10	26	12	20	4	12	1	1	3	652	35
1982	128	2	623	18	98	3	21	4	7	0	9	1	886	28
1983	36	0	96	0	13	0	6	0	10	0	2	0	163	0
1984	64	2	199	5	60	3	8	4	19	3	12	1	362	18
1985	69	66	178	130	31	42	12	12	20	27	10	11	320	288
1986	44	97	155	208	74	36	119	65	8	7	3	3	403	416
1987	19	30	100	43	11	17	6	7	4	11	18	0	158	108
1988	16	28	96	33	33	22	26	17	4	22	0	3	175	125
1989	21	49	148	104	94	274	74	50	21	23	10	0	368	500
1990	189	275	174	275	36	75	13	5	13	20	6	3	431	653
1991	34	75	63	45	50	38	7	13	16	39	22	20	192	230
1992	27	53	56	117	44	116	16	36	2	4	0	0	145	326
1993	30	166	76	245	16	29	3	10	0	0	0	0	125	450
1994	0	52	0	38	5	35	0	25	3	15	0	0	8	165
1995	0	60	0[b]	165	0	50	0	0	0	25	0	0	0	300
1996													0	400
1997													0	300
1998													0	250
1999													0	200

* Season closure on Oct. 15

[a] = Season closure August 13

[b] = Catch and release only, effective June 7

Figure 8.2.2.1. May and June catch rates on the Penobscot River from 1979 to 1995, with no reduction in catch rate as returns declined.

In 1995, the ASA promulgated emergency regulations closing all Maine rivers to harvest of Atlantic salmon during July and August. In 1996, all Maine rivers had catch and release regulations, allowing no harvest, and directed fisheries also had regulations of fly fishing only in inland waters, hook and line only in coastal waters, prohibition on the use of tailers in landing and releasing salmon, and restrictions limiting landing nets to knotless materials, not to exceed 0.5 inch mesh. All directed fisheries for Atlantic salmon in the state have been closed since January 1, 2000.

Trial (2005) produced a probabilistic estimate of the number of salmon killed as the result of hook and release fishing on the Penobscot River from 1996 to 1999. Data from the fishery (1979 to 1995), adult captures at the Veazie Dam and literature on Atlantic salmon angling mortality were used to derive catch rate parameters for simulations within three periods: May and June; July and August; and September and October. For the simulations, hooking mortality was drawn from a uniform probability distribution with the ranges: 0.001 (99.9% survival) to 0.20 (80% survival) for cool water (spring and fall periods) and 0.05 (95% survival) to 0.30 (70 % survival) for the summer period. The ranges were chosen based on a literature review and represent reasonable mortality rates based on the thermal conditions during the two-month periods. Hooking mortality was assumed to be uniform over all groups (origin, sea-age, and sex groups). These simulations predicted median mortality of approximately 4% of the annual returns during the period of catch and release angling; representing from 40 to 75 fish. Comparable simulations are not available for other rivers where catch and release angling was allowed.

These simulations are being used to develop a one-year experimental catch and release fishery. The fishery will be located in a short reach of the Penobscot River below Veazie dam where anglers would target late returning sea-run salmon during a one-month period in September and October. The fishery would occur after broodstock were collected for the year. Fish caught and released in this fishery will be physiologically stressed and a portion will die, affecting the spawning population.

8.2.3 Illegal In-River Harvest of Adult Atlantic Salmon

Poaching (i.e., illegal in-river harvesting) like angling mortality, is additive to natural mortality and directly reduces the spawning populations in rivers. With the abundance of returning adults well below conservation spawning escapement, even low levels of poaching will adversely affect Atlantic salmon populations.

The Maine Conservation Plan (1997) reported that during the mid-1980s there were 10 to 15 poaching cases reported each year; however, only four cases were reported between 1992 and 1996 (MASTF 1997). In 1998, vandals killed the one documented returning Atlantic salmon to the Dennys River. Following the closure of Atlantic salmon fisheries statewide, anglers on the Penobscot River illegally fished under the guise of intending to capture striped bass in traditional salmon pools. As a result of documented poaching, the Commissioner of MDMR closed the Penobscot River from the Veazie Dam to the pipeline to all fishing in July of 2000. In 2003, two Atlantic salmon kelts were reportedly harvested on the Sheepscot River, with the angler identifying them as brown trout (*Salmo trutta*). Similarly, the MASC received reports in 2002 of an Atlantic salmon being harvested on the Penobscot River and identified as a landlocked salmon by the angler. MDIFW game wardens also reported angling activity on the Penobscot River directed at Atlantic salmon in 2003 and 2004. In 2002, there were reports of fish being poached on the Narraguagus River during the shad run.

The MASC has taken steps to prevent harvest of sea-run Atlantic salmon under the guise of misidentification as brown trout or landlocked salmon. Maximum legal size (25 inches) regulations have recently been implemented on rivers known to contain anadromous Atlantic salmon. The MASC continues to work with MDIFW regional fisheries biologists to extend the 25 inch maximum length regulation to protect adult Atlantic salmon in riverine habitat throughout the state. In 2003, MASC and MDIFW closed a segment of the Narraguagus River below the ice control dam in Cherryfield to all fishing, by emergency action, from August 22 to the end of the open-water fishing season to prevent Atlantic salmon angling/poaching on the Narraguagus during the shad run. This closure remains in effect each year except from May 1 to June 10.

In addition to regulations, enforcement activities have been directed at this illegal activity. Using funds provided by the Maine Outdoor Heritage Program, MDIFW added two additional seasonal wardens during 1997 and 1998 to focus on enforcement of angling regulations for the protection of Atlantic salmon. Funds for the continuation of this expanded surveillance work were not provided in 1999 (LWRC 1999) or beyond. Atlantic salmon enforcement activities have shifted to wardens on staff and to collaborative efforts with federal agents. As an example, in 2003 Maine wardens

documented a total of 676 hours and checked 341 anglers on seven salmon rivers. The Maine Warden Service has developed a training unit for staff to improve Atlantic salmon enforcement. Federal enforcement officers and the Maine Warden Service are working together on surveillance and investigations related to poaching activities, but details are not available due to the potentially sensitive nature of this information.

8.2.4 By-catch of Atlantic Salmon in State Recreational and Commercial Fisheries

Recreational angling occurs for many species of freshwater fish throughout the range of the GOM DPS. The potential exists for anglers to misidentify juvenile Atlantic salmon as brook trout, brown trout, or landlocked salmon. In certain portions of the Narraguagus River, a minimum size (8 inches) restriction on trout caught after June 30 of each year reduces the potential for keeping salmon parr misidentified as another salmonid species. Atlantic salmon kelts may also be taken by ice fishermen who mistake them for landlocked salmon. A maximum length for landlocked salmon and brown trout (25 inches) was adopted in an attempt to avoid this potential source of accidental sea-run Atlantic salmon harvest in winter and in estuaries. Nevertheless, as more anglers target striped bass populations, the potential for striped bass anglers to catch Atlantic salmon in estuaries will likely increase.

The biological effects that incidental catch and subsequent release may have on Atlantic salmon are not well understood (Brobbel et al. 1996). Several studies have concluded that exhaustive exertion associated with angling may result in significant physiological disturbances including mortality (Bouck and Ball 1966, Beggs et al. 1980, Graham et al. 1982, Wood et al. 1983, Brobbel et al. 1996). While studies conducted under controlled or laboratory settings have resulted in zero mortality to Atlantic salmon caught and properly released, it is highly unlikely that such favorable conditions would be consistently present in the natural environment. Conditions that contribute to mortality include elevated water temperatures, exposure of the fish to air after it has been captured, extremely soft water, low oxygen levels, low river flow and improper handling (Booth et al. 1995).

Although the MASCP included the goal of reducing incidental angling mortality by 50%, MDIFW has stated that they have no way of estimating the number of Atlantic salmon caught as bycatch in other recreational fisheries or to estimate the resultant mortality (LWRC 1999). MDIFW further suggested that the effectiveness of regulatory changes should be evaluated based on scientific studies and the knowledge of the MASC regarding salmon survival and mortality, rather than a survey of anglers or another monitoring effort due to concerns about angler identification of juvenile Atlantic salmon. In short, little quantitative data exists that would allow a meaningful estimation of the number of anadromous Atlantic salmon incidentally captured by recreational anglers within the range of the GOM DPS.

8.2.5 Native American Subsistence Fisheries

Native American Tribes that once freely occupied the geographic area that is now called Maine, had a long and intertwined cultural, spiritual, and subsistence relationship with Atlantic salmon and other native diadromous fish species. Treaties with the then state of

Massachusetts, in the early 19th century, while apparently ceding to European colonists much of the land base that Native Americans once traversed freely, also affirmed the rights of these tribes to utilize salmon and other fish and wildlife resources for purposes of subsistence and sustenance (which includes the cultural and spiritual connections to these resources). For decades thereafter, tribes continued practicing traditional methods as long as harvestable numbers of sea-run fish were available in their remaining territories.

With the Federal recognition of Maine tribes as independent sovereigns, and with rights to self determination, in the mid-1970s, Maine tribes began to pursue a land claim to about 2/3 of the land within Maine. After several years of legal confrontation and negotiation, the Maine Indian Claims Settlement Act of 1980 (25 USC 1721; PL 96-420) was signed. Among other things, this and its complementary "Implementing Act" (30 MRSA Pt. 4, Chapter 601) re-affirmed the Penobscot Indian Nation's (PIN) aboriginal rights to take fish from their Reservation (Penobscot River upstream of and including Indian Island, as also established therein) for sustenance purposes. Thus, tribal members can legally utilize Atlantic salmon from Reservation waters for sustenance, independent of regulations in place for commercial and recreational fisheries. The PIN has developed its own permitting system and regulations for these sustenance activities. However, to date, they have taken a total of only two salmon under this authority, and none since 1988, due to the dire status of the species in Maine waters.

8.2.6 Impacts of Scientific Activities

Mortality due to handling fish in critically low populations has the potential to compound extinction risks (NRC 2004). Risks and benefits of monitoring and research should be carefully weighed to ensure that the benefits outweigh the risks of death or injury. Sampling naturally-reared parr and smolts may carry even larger risks because each individual is thought to have a greater likelihood of survival to spawn than a hatchery-origin individual (USASAC 2005).

Since 2000, capturing, collecting, or handling of endangered Atlantic salmon (within the range of the GOM DPS as listed in 2000) has been subject to authorizations issued under section 10(a)(1)(A) of the ESA. This monitoring and research has been conducted by a variety of entities. The MASC and NMFS have conducted population assessment work within the DPS (as listed in 2000). Faculty and graduate students at the University of Maine, USGS physiologists, and the USFWS have conducted research projects in rivers within the DPS (as listed in 2000) or using DPS fish (as listed in 2000) in laboratory research. Since 2000, these same entities have been active in scientific investigations on the Penobscot and other rivers in Maine. Assessment and research supports Atlantic salmon recovery efforts throughout the region by quantifying abundance and mortality at critical life history stages to identify population bottlenecks. Thus, assessment losses are balanced by the benefits of having data on the status of populations at a variety of life stages to understand survival and adaptively manage stocking practices (timing, life stage, methods), physical habitat, predators, and water quality and quantity.

Atlantic salmon population assessment activities include capturing and handling fry emerging from redds, juvenile salmon (age 0 and age 1) using electrofishing, smolt in

rotary screw traps and surface trawls, and adults at fishway traps and weirs. Research projects have encompassed all juvenile life stages and adults on several rivers. These monitoring and research activities have also involved marking (fin excision, injected elastomer), tagging (PIT, ultrasonic), removing scales for ageing, collecting blood and tissue, surgeries requiring anesthesia, and sacrificing of individual fish.

8.2.6.1 Freshwater Assessment

Research and monitoring generally have little demographic effects on robust salmon populations; however, effects on small populations could be significant if natural mortality during the life stage handled was expected to be low (NRC 2004). Reported mortality rates for freshwater stages are quite high, with minimum mortality for each life stage being 40% or greater (Legault 2004). When mortality from a factor is additive, any increase in mortality results in an increase in total mortality. When mortality from a factor is compensatory, a population's total mortality remains unchanged at low to intermediate death rates caused by the factor, because natural mortality decreases in response to reduced density. Compensatory mortality is more likely in populations regulated by density dependant factors (i.e., food, space) like juvenile Atlantic salmon.

Natural annual flows which Atlantic salmon experience includes summer low flows in July, August, and September and winter low flows in January and February. Survival of juvenile salmon is positively related to summer and winter discharges (Gibson 1993), with better survival in years with higher flows during these seasons. Higher survival results in higher densities because discharge determines the amount of available habitat with suitable depth and velocity in the river. Wankowski and Thorpe (1979) suggest the density of juvenile Atlantic salmon is dictated by the availability of profitable feeding areas and water velocity because these factors determine territory size. The defense of individual feeding territories is the mechanism limiting population density (Chapman 1966) and results in self-thinning of juvenile Atlantic salmon populations (Grant 1993). Self-thinning is a decrease in population density that results from intraspecific competition as individuals increase in size and compete for space. As age 0 and age 1 parr grow through the summer their territory size increases, however, in most years the available habitat is decreasing as flows decline to seasonal lows. In winter, fish shelter in the substrate and the number of suitable over-wintering sites may limit population size and fish that have not gained adequate energetic reserves may not survive the winter. Pre-winter energy reserves are required because juvenile weight loss normally occurs from November through January (Egglishaw and Shackley 1977). In addition to these density dependent factors, extreme hydrologic conditions, ice, and low pH have the potential to cause high density-independent mortality. With Atlantic salmon populations regulated by both density dependant and independent factors, sampling mortality could be additive or compensatory, depending on sampling timing relative to population size and potential natural mortality.

The Narraguagus is sampled extensively, with approximately 300 units (100 m^2) electrofished annually to develop depletion estimates (usually three runs per site). The Narraguagus contains 6,013 units of juvenile rearing habitat; thus, sampling occurs in

slightly less than 5% of the rearing habitat. Despite sampling that portion of the habitat, MASC annually handles approximately 4.5% of large parr population based on basin wide estimates from 2001 to 2004 (Table 8.2.6a). The percentages differ because not all sampled habitat is equally productive. By adapting scap net size and shape to habitat conditions and salmon size class, and having crews stop sampling events if mortality is observed, MASC electrofishing mortality has decreased since 2001 (Table 8.2.6b). Where juvenile densities are low, MASC substitutes one run sampling for depletion estimates. In addition, snorkeling surveys are used where the objectives of sampling can be accomplished with visual counts. With these operational changes, documented electrofishing mortality of large parr during MASC electrofishing surveys in the Narraguagus has been less than 0.1% of large parr population based on basin wide estimates from 2001 to 2004. These mortality estimates are minimum estimates, but they do represent the most current assessment of sampling mortality for Atlantic salmon in Maine

In recent years, there have been a number of journal articles and reviews on the deleterious effects of electrofishing on individual fish. However, most authors did not consider the issue in a broader demographic context: the proportion of the population exposed to sampling and the likelihood that electrofishing mortality (either immediate or delayed) would be compensatory and not additive. Schill and Beland (1995) were first to call for fisheries and policy professionals to put the studies into a population context. Snyder (2003), in a review of the effects of electrofishing, notes that mortalities are related to asphyxiation that are often the result of poor handling. He states that injuries heal and seldom result in delayed mortality and that electrofishing is unlikely to have a population effect if it is conducted carefully and the proportion of the population sampled is small. He cautions that alternatives to electrofishing are not acceptable where their use jeopardizes critical comparisons with past data. He further cautions that alternative collection methods could cause more mortality or injury than electrofishing and should not be adopted without careful evaluation of its effects on both the individual fish and the population as a whole.

Table 8.2.6a. Narraguagus River electrofishing mortality compared to an average expected natural mortality for the number of fish handled and expressed as a proportion of an approximate basinwide population estimate. The number of large parr removed from the river and taken to Craig Brook National Fish Hatchery is presented for reference.

POPULATION	**2001**	**2002**	**2003**	**2004**
Large Parr Handled Electrofishing	917	792	882	913
Percentage of Approximate* Basinwide Estimate	4.6%	4.0%	4.4%	4.6%
ELECTROFISHING MORTALITY				
Number of Mortalities	13	2	5	0
Percent of Fish Handled	1.4%	0.3%	0.6%	0.0%
Percent of Approximate* Basinwide Estimate	0.1%	0.0%	0.0%	0.0%
NATURAL MORTALITY				
Predicted Natural Mortality of Handled Fish	307	265	295	306
Percent of Approximate* Basinwide Estimate	1.5%	1.3%	1.5%	1.5%
BROODSTOCK				
Taken to Craig Brook National Fish Hatchery	282	260	264	246

* Basinwide estimate calculations are currently estimated at 20,000 but are being recalculated.

Table 8.2.6b. Mortality of juvenile Atlantic salmon handled during 2001, 2002, 2003, and 2004 MASC electrofishing activities within DPS watersheds.

Life Stage-Activity Purpose	**2001**	**2002**	**2003**	**2004**
YOY-Population Estimate	2.72%	1.99%	1.95%	0.78%
Parr-Population Estimate	0.50%	0.80%	0.31%	0.08%
Parr-Broodstock Collection	0.11%	0.02%	0.07%	0.05%
Total Number of Fish Handled	3792	4017	4211	6372

8.2.6.2 Early Marine Studies

Marine mortality of Atlantic salmon is high, with only between 0.05% and 4% of smolts surviving to return as 2SW fish (Legault 2004). The mortality rate of a fish is inversely related to its weight (Matthews and Buckley 1976). Therefore, as an Atlantic salmon ages and grows in the marine environment it is more likely to survive to return and reproduce. This means that mortality would be highest for postsmolts, the smallest life stage in the marine environment. There are other reasons to expect that mortality would be higher during the postsmolt stage of marine life. Atlantic salmon smolts are analogous

to larval fish in that they are the initial life stage in the marine environment. Survival during the transition requires growth based on new food sources and avoiding capture by a novel suite of predators, both related to significant losses in larval fishes (Letcher et al. 1995) and both potentially density-dependent factors. While mortality at this life stage is thought to be quite high (USASAC 2005), it may not be as high as previously assumed (LaCroix et al. 2004, LaCroix and McCurdy 2005, LaCroix and Knox 2005).

Assessments and research projects that focus on Atlantic salmon smolts estimate freshwater emigrants, quantify estuarine behavior using telemetry, and examine coastal movements and ecology using postsmolt trawls. Handling mortality associated with smolt population assessment is very low (Table 8.2.6.2a). Further, a low proportion of the population in each river is handled. Smolt mortality in the Penobscot River is higher because fish are collected downstream of several hydropower dams and those fish are subject to fish passage stress (see section 8.1). There is also more intensive research sampling of smolts on the Penobscot River (blood plasma sampling). However, only 6,475 smolts (hatchery and naturally reared combined) were captured between 2000 and 2004. During the same time period, over 2.5 million smolts were stocked (roughly 500,000 annually). Thus, a very low proportion of the overall smolt population is handled each year.

In 2004, ultrasonic telemetry was used to monitor 354 smolts in the Narraguagus (n=74), Pleasant (n=124) and Dennys Rivers (n=156). While surgery is intrusive, published data (LaCroix and McCurdy 1996) and trials holding fish at Green Lake National Fish Hatchery suggest both initial and longer-term mortality is minimal. Hatchery fish were used to train surgeons and evaluate their skills prior to the field season. Hatchery staff monitored these fish for at least 13 days following surgery and all 256 (100%) survived until release (NOAA, unpublished data). These rates are comparable to non-surgical fish at this hatchery. In the wild, staff attempted 100 surgeries, 98 were successful. The knowledge gained from these studies has lead to substantial advances in understanding early marine mortality, and directly lead to management programs that may well enhance survival.

Table 8.2.6.2a. Mortality (M) associated with capture in rotary screw traps for selected Maine rivers in 2004.

Population	Year	Handled	#DOA	%DOA	Sampling/ Trapping M#	Sampling M%	Total M
Narraguagus	1997-2004	5746	3	0.05%	34	0.59%	0.64%
Pleasant	2003-2004	1277	3	0.23%	0	0.00%	0.23%
Sheepscot	2001-2002; 2004	312	2	0.64%	1	0.32%	0.96%
Penobscot	2000-2004	6475	560	8.65%	180	2.78%	11.43%

The NMFS annually conducts a postsmolt trawl survey to collect biological information on hatchery and naturally reared postsmolts in Penobscot Bay. The survey is conducted by pair-trawling using a modified pelagic trawl net specifically designed and operated to

minimize stress and injury to the fish. After sampling, the fish are immediately returned to a large recovery tank where they remain for up to an hour until full recovery from the sampling procedures is evident. While every attempt to minimize stress and injury to the fish is taken, some individuals inevitably expire from either stress induced from the sampling procedures or from the trawl operation itself (Table 8.2.6.2b). The likely cause of each mortality was recorded from 2003 to 2005 (Table 8.2.6.2c). Since 2003, sampling trawl induced mortalities have remained low and have decreased. This reflects the increased experience of the scientific crews and fishing crews as well as gear modifications and sampling improvements designed to make the fishing and handling process as benign as possible. Post-release mortality has not been assessed.

Table 8.2.6.2b. Total postsmolts captured, recorded mortalities, and percent mortality in the postsmolt trawl from 2001 to 2005.

Year	Total Postsmolts Captured	Mortalities Recorded	% Mortality
2001	1,458	118	8.09
2002	739	30	4.06
2003	488	53	10.86
2004	697	41	5.88
2005	745	34	4.56
Total	4,127	276	6.69

Table 8.2.6.2c. Total postsmolts captured, percent trawl induced mortality, and sampling induced mortality in the postsmolt trawl from 2003 to 2005.

Year	Total Postsmolts Captured	% Trawl Induced Mortality	% Sampling Induced Mortality
2003	488	4.71	6.15
2004	697	2.15	3.73
2005	745	3.22	1.34
Mean Mortality		3.36	3.74

Research or monitoring that has the potential to kill pre-spawn adults in freshwater is of greatest concern because any mortality is likely additive to natural mortality. On the Penobscot River, the fish handled at the Veazie fishway trap represent the entire return to the river above that point. Similarly, a trap on the Narraguagus and weirs on the Dennys and Pleasant Rivers have resulted in a high proportion of the returns to these rivers being handled. These facilities are not 100% effective because Atlantic salmon can jump the Narraguagus River Ice Dam and the weirs are not in place for the entire year. Of the 50,486 fish handled at the Veazie trap (including recaptures) from 1978 to 2004, 133 (0.26%) were reported as handling mortalities and 123 (0.24%) were sacrificed for research projects. On the Narraguagus River, there have been no reported trap handling mortalities from 1991 to 2004. Weirs on the Dennys and Pleasant River have been operated for a limited number of years. In that time, 17 fish have been handled on the

Pleasant River (2000 to 2004) and 31 on the Dennys River (2000 to 2004) with only one mortality on the Pleasant River.

8.2.7 Educational Uses

Other research projects and educational programs (e.g., salmon in schools) handle primarily fish in excess of those required for recovery programs. Thus, any resultant mortality from these programs is thought to have no demographic effect.

8.3 Predation, Disease, and Competition

8.3.1 Predation

Predation is a natural and necessary process in properly functioning aquatic ecosystems. Atlantic salmon have evolved a suite of strategies that allow them to co-exist with the numerous predators they encounter throughout their life cycle. However, natural predator-prey relationships in aquatic ecosystems in Maine have been substantially altered. The historical predator assemblage and the impacts of several anthropogenic changes are discussed below.

8.3.1.1 Historical Predator Assemblage

Native freshwater fishes known to prey upon Atlantic salmon within the range of the GOM DPS include brook trout (*Salvelinus fontinalis*), burbot (*Lota lota*), American eel (*Anguilla rostrata*), fallfish (*Semotilus corporalis*), and common shiners (*Luxilus cornutus*) (van den Ende 1993, Anthony 1994, Baum 1997). Brook trout and American eel are likely the two most important native piscine predators of Atlantic salmon. Both brook trout and American eel are native to all the major drainages in Maine. Only large brook trout (>10 inches) are expected to prey upon juvenile Atlantic salmon (MASTF 1997) although smaller trout may feed on salmon eggs after they are deposited in the gravel (White 1939). Elson (1941) and Godfrey (1957) reported substantial predation on salmon fry and parr by American eels. Although eels may feed upon juvenile salmon with some regularity, they pose little if any threat to smolt size or larger salmon. In addition, the fallfish (*Semotilus corporalis*) may be a potential predator of salmon fry and parr considering the degree of sympatry in many rivers. The few dietary studies of the fallfish confirm their piscivory (Kingsbury 1977, Gibbs et al. 1979), but the extent to which they prey on salmon is largely unkonwn. Overall, freshwater fish predators native to Maine pose little threat to the GOM DPS.

In estuarine and marine environments, striped bass (*Morone saxatilis*), Atlantic cod (*Gadus morhua*), pollock (*Pollachius* spp.), porbeagle shark (*Lamna nasus*), Greenland shark (*Somniosus microcephalus*), Atlantic halibut (*Hippoglossus hippoglossus*), and many other fish species have been recorded as predators of salmon at sea (Hvidsten and Møkkelgjerd 1987, Mills 1989, Mills 1993, Beland et al. 2001). While many fishes are known to prey on salmon, their effect is difficult to determine. The fishes mentioned above have eaten salmon, but extensive surveys of stomach contents of the same fish have been completed without any stomachs containing salmon remains (Mills 1993). Of the aforementioned fishes, striped bass have the highest likelihood of consuming

substantial amounts of salmon because striped bass often feed in narrow estuaries that salmon smolts must pass through. Substantial smolt predation has recently been documented in the Connecticut (Schulze 1996) and Merrimack (Blackwell and Juanes 1998) Rivers. However, the immigration of striped bass in most rivers in Maine occurs after the majority of the smolt emigration; although, some level of predation is known to occur when they overlap (Beland et al. 2001). The major exception to this pattern is in Merrymeeting Bay where striped bass are known to overwinter. Unfortunately, no studies to date have examined the extent of spatial and temporal overlap of striped bass immigrations and smolt emigrations within the range of the GOM DPS. In fact, little quantitative information exists that would allow a meaningful analysis of the relative importance of each of the marine fish predators of Atlantic salmon at this time (Cairns 2001a).

Many species of birds also prey upon Atlantic salmon throughout their life cycle including red-breasted mergansers (*Mergus serrator*), common mergansers (*M. merganser*), belted kingfishers (*Ceryle alcyon*), barred owls (*Strix varia*), bald eagles (*Haliaeetus leucocephalus*), ospreys (*Pandion haliaetus*), double crested cormorants (*Phalacrocorax auritus*), northern gannets (*Morus bassanus*), black-backed gulls (*Larus marinus*), common murres (*Uria aalge*), black-legged kittiwakes (*Rissa tridactyla*), shearwaters (*Puffinus* spp.), and northern fulmars (*Fulmarus glacialis*) (Amiro 1993, Anthony 1994, Baum 1997, Cairns 1998, Cairns and Reddin 2000). In freshwater environments, mergansers and kingfishers are likely the most important predators of Atlantic salmon. Most evidence suggests that mortality due to mergansers and kingfishers is compensatory rather than additive (Cairns 2001b). In estuarine environments, double crested cormorants have likely always been an important predator of smolts as they transition to life at sea because osmotic stress due to sea water entry likely enhances the predation risk at this life stage (Handeland et al. 1996), and predation at this life stage is likely additive rather than compensatory (Cairns 2001b). However, the abundance of alternative prey resources (e.g., the alewife) likely minimized the impacts of cormorant predation on the GOM DPS historically (see section 3 for a detailed review). In the marine environment, northern gannets are likely an important predator of postsmolts because of their large body size and specialized feeding techniques (Montevecchi et al. 2002). Other seabird predators are only able to feed on post smolts for relatively short time windows each year (Cairns and Reddin 2000). Postsmolts out-grow northern fulmars, black-legged kittiwakes, and common murres by early July; shearwaters by late July; and gulls by early September (Cairns and Reddin 2000).

Both mink (*Mustela vison*) and otter (*Lontra canadensis*) are also known to prey upon Atlantic salmon (Heggenes and Bergstrom 1988, Baum 1997). Little is known about the extent to which mink and otter prey on Atlantic salmon but predation by endothermic predators in winter may be substantial especially if over-wintering habitat is limited (Cunjak 1996).

Several species of seals also prey on Atlantic salmon in estuarine and marine areas. Generally, salmon are only a small component of overall seal diets (Cairns and Reddin 2000). However, that does not necessarily mean that their impact on salmon populations

is minimal. The annual consumption of food by seals in the Northwest Atlantic is on the order of four million tons (Hammill and Stenson 2000) while the biomass of postsmolts in the same area is on the order of 700 tons (Cairns 2001a). Thus, seals could exert a substantial exploitation rate on salmon populations even if salmon are a small fraction of their overall diet (Cairns 2001a). For example, if postsmolts represented 0.24% of the diet of harp seals when they exist in sympatry in the fall, then the entire postsmolt cohort of the entire Northwest Atlantic would be consumed (Cairns and Reddin 2000). Harbor seals (*Phoca vitulina*) may also consume adult salmon as they return to their natal rivers to spawn. Some evidence suggests that the incidence of seal wounds has increased as seal populations continue to rebound (Baum 1997). However, no studies to date have been conducted that would allow for a quantitative estimate of the number of adults consumed.

The extent of predation by other marine mammals is still poorly understood. The only indication that cetaceans may prey on salmon is from a single salmonid otolith found in a harbor porpoise (*Phocoena phocoena*) stomach (Cairns 2001a); although, Thompson and Mackay (1999) suggest that odontocete cetaceans may have inflicted many of the marks attributed to seals. Without meaningful consumption estimates, it is currently impossible to assess the impacts of cetacean predation. However, the distribution of several odontocete cetaceans clearly overlaps the distribution of Atlantic salmon. Furthermore, Pacific salmon (*Oncorhynchus* spp.) have been reported from the stomachs of nine species of cetaceans (Fiscus 1980). Thus, cetaceans may harvest a substantial portion of Atlantic salmon biomass even if salmon are a small portion of their diet (Cairns 2001b).

8.3.1.2 Contemporary Predator Assemblage and Interactions

Natural predator-prey relationships in aquatic ecosystems in Maine have been substantially altered by non-native species interactions; habitat alterations; site-specific and cumulative delay, injury, or stress experienced during migration and passage over/through dams; and the declines of other diadromous fishes. In some cases, the effects of these perturbations are well understood while some relationships are more speculative.

<u>Non-native fishes</u>

A variety of non-native fishes have been stocked throughout the range of GOM DPS. Those that are known to prey upon Atlantic salmon include smallmouth bass, largemouth bass (*Micropterus salmoides*), chain pickerel (*Esox niger*), northern pike (*Esox lucius*), rainbow trout (*Oncorhynchus mykiss*), brown trout, splake (*Salvelinus namaycush* X *Salvelinus fontinalis*), yellow perch (*Perca flavescens*), and white perch (*Morone americana*) (van den Ende 1993, Baum 1997). Yellow perch, white perch, and chain pickerel were historically native to Maine, although their range has been expanded by stocking and subsequent colonization (MDIFW 2002).

Smallmouth bass and chain pickerel are each important predators of Atlantic salmon within the range of the GOM DPS. Smallmouth bass are a warm-water species whose range now extends through north-central Maine and well into New Brunswick (Jackson

2002). Smallmouth bass now inhabit many of the same areas used by juvenile Atlantic salmon including upstream rearing habitat (e.g., East Branch Penobscot River). Smallmouth bass likely feed on fry and parr though little quantitative information exists regarding the extent of bass predation. Smallmouth bass may also be important predators of smolts in main stem habitats. Although van den Ende (1993) did not document any consumption of smolts by smallmouth bass in the Penobscot River, he predicted that smolt consumption could be as high as 10 smolts per bass per day. Though little empirical data has been published from Maine waters, smolt predation by smallmouth bass has been observed anecdotally and substantial levels of smolt predation by smallmouth bass have been observed in Pacific salmon populations (Rieman et al. 1991, Tabor et al. 1993). Hatchery smolts appear to be particularly vulnerable to bass predation after water temperatures rise to around 10°C, the time when smallmouth bass become more active metabolically (van den Ende 1993). Figure 8.3.1.2 illustrates that the majority of the hatchery-origin smolt run in the lower Penobscot occurs after water temperatures exceed 10°C. Timing of migration of smolts from natural reproduction or fry stocking in the Penobscot can occur even later. For example, peak dates for wild smolts from the East Branch Penobscot moving past the Mattaceunk Hydropower Project, some 60 miles upstream of the capture sites represented in Figure 8.3.1.2, ranged between May 19 and June 3 over five years of monitoring (GNP 1995). These wild smolts would then be moving downstream at even warmer average water temperatures than the hatchery-origin smolts. Therefore, smallmouth bass predation on migrating smolts remains a substantial concern despite the paucity of quantitative information.

Figure 8.3.1.2. Hatchery smolt run timing in relation to water temperature in the lower Penobscot River in 2003 (NOAA unpublished data).

Chain pickerel are known to feed upon smolts within the range of the GOM DPS and may feed on younger life stages as well. Chain pickerel can be quite active in temperatures below 10°C (van den Ende 1993, MDIFW 2002). Smolts were, by far, the most common item in the diet of chain pickerel observed by Barr (1962) and van den Ende (1993). The extent of chain pickerel predation in any given river is expected to vary in proportion to the amount of deadwater areas that juvenile salmon must pass as pickerel prefer these areas. Though little quantitative information exists, dams create slow water that is preferred by chain pickerel and concentrate emigrating smolts in these head ponds by slowing migration speeds (McMenemy and Kynard 1988, Spicer et al. 1995). Ruggles (1980) suggested that these changes in habitat conditions likely increased smolt predation by northern pike, whose niche is quite similar to chain pickerel. Northern pike have also been stocked in Maine, and recent reports suggest that their range now includes Pushaw Lake which drains to the Lower Penobscot River (Gordon Kramer, MDIFW, personal communication). Populations now exist in at least 16 lakes within the Kennebec and Androscoggin drainages (MDIFW 2001)

Brown trout predation has been implicated in the decline of several native salmonid populations in North America (Moyle 1976, Sharpe 1962, Alexander 1977, Alexander 1979, Taylor et al. 1984). Brown trout consume large numbers of stocked Atlantic salmon fry (MASC and MDIFW 2002). The remaining non-native fishes (i.e., rainbow trout, splake, largemouth bass) also likely prey on Atlantic salmon juveniles when they live in sympatry. Little quantitative information is available on the extent of these interactions, however.

Habitat Alterations

Structural simplification of river channels and impoundment of formerly free-flowing rivers likely influence predator prey dynamics within the range of the GOM DPS. Simplified river channels resulted from past forestry practices whereby impediments to log driving were removed. Large boulders and large woody debris (LWD), that likely created a mosaic of diverse microhabitats, were often removed because these features would stop the efficient passage of logs (see section 8.1 for a detailed review). Reducing the diversity of habitat types available to juvenile salmon may increase predation risks especially in winter (Cunjak 1996). To avoid diurnal, endothermic predators but still feed enough to remain somewhat active in winter, juvenile Atlantic salmon are photonegative in winter (Rimmer et al. 1984, Rimmer and Paim 1990, Valdimarsson et al. 1997, Valdimarsson and Metcalfe 1998), hiding in low light environments beneath the substrate during the day, and actively feeding out in the open only during the dark of night. Although feeding efficiency is reduced in low light environments (Fraser and Metcalfe 1997), Valdimarsson et al. (1997) hypothesized that because metabolic rates are low in winter, feeding only at night when there is less risk of predation can fulfill energy requirements. Overhanging banks, root wads, woody debris, surface ice and depth also create low light conditions that over-wintering parr generally prefer and therefore may also provide refuge from visual predators.

Further habitat alterations included impounding free flowing river segments. Dams increase the total surface area, volume, and depth of the upstream river segment; lower ambient current velocities compared to natural conditions; and lead to more rapid warming of water temperatures during normal smolt migration windows. These conditions result in: (1) a greater volume of ideal year-round habitat for known fish predators of salmon smolt, such as smallmouth bass and chain pickerel, and foraging habitat for avian predators such as double crested cormorants; (2) an easing of the physical challenges faced by these predators in catching their prey; (3) significant modification of migratory cues leading to disorientation and delays and increasing exposure time to predators. These factors likely increase vulnerability of smolt to predation in impounded rivers (Larinier 2000). DeAngelis et al. (2001) noted the importance of the spatial scale of predator behavior and prey behavior in modeling predator-prey dynamics for migrating smolts. Relatively stationary predators and closely timed schools of migrating smolts resulted in the lowest modeled predation losses.

Radio tag studies on the Penobscot River, by hydropower project licensees (e.g., Bangor Hydro 1994) and others (Spicer et al. 1995) consistently report significant delays in smolt passing hydropower dams once reaching the forebay area. During these studies, Penobscot River smolt move passively downstream at speeds slightly slower than the ambient water velocity. Given this pattern, smolts would have and increased vulnerability to predation in impounded reaches.

Blackwell and Krohn (1997) indicated strong habitat selection by cormorants in favor of main stem and larger tributary impoundments proximate to turbine forebays and tailraces. In a corollary study, Blackwell et al. (1997) reported that salmon smolts were the most frequently occurring food items in cormorant sampled at main stem dam foraging sites. Foraging behavior of cormorants was characterized in Blackwell and Krohn (1997) as follows:

> "Cormorants were observed resting on structures and exposed areas of rocks and sandbars. In headponds, birds foraged along the spillway and in areas proximate to turbine intakes. Below headponds, birds foraged under spillways, in tailraces, and at areas proximate to the exits of turbine draft tubes."

This study also reported that most cormorants left forebay areas shortly after smolts had moved past these potential foraging sites.

Dam Passage

The site-specific and cumulative delay, injury, and stress factors experienced during migration and passage over/through dams also increases predation risks. Dam passage negatively affects predator detection and avoidance in salmonids (Raymond 1979, Mesa 1994, Blackwell et al. 1997). Smolts arriving at a hydro project forebay or spillway encounter unnatural features such as metal trash racks, rapidly accelerating current velocities, and contrast in ambient lighting, causing delays and disorientation. Once smolt choose a route for passing a hydropower dam, the ramifications of that choice with respect to their subsequent vulnerability to predation can vary considerably. However,

even with the most benign passage route and experience (i.e., in theory, a formal, prescribed downstream bypass system), some disorientation is inevitable immediately after passage, potentially leading to increased vulnerability to predation. Choosing less benign passage routes (e.g., turbine passage or spillway passage into insufficiently flowed spillway bypass segments) can often result in sublethal lacerations and trauma, scale loss (leading to diminished protection from disease and fungus), and a general diminishment of smolt vitality. These factors in turn lead to a further increase in vulnerability to predation, especially as these effects accumulate over multiple dam passages.

Similarly, delays of adult salmon attempting to locate and pass an upstream passage facility at a dam could increase exposure to predators. Delays in adult upstream migration at dams could also work in unison with stressful summer water temperatures (Power and McCleave 1980) to further increase vulnerability to predation. Finally, similar to the smolt situation, these delays can act cumulatively over multiple events to progressively weaken the adult, again increasing its vulnerability to predation.

Declines of other diadromous fishes

Prior to European settlement, several other native diadromous species were more abundant than they are today. Many U.S. and southern Canadian rivers historically supported large and diverse anadromous fish populations including alewife, blueback herring, American shad, and rainbow smelt (*Osmerus mordax*) in addition to Atlantic salmon. These populations likely served as an important forage-base buffer allowing opportunistic predators to focus on more abundant and energy rich prey species (see Section 8.5 for a detailed review).

8.3.2 Disease

Atlantic salmon are susceptible to a number of diseases and parasites which can result in high mortality. Disease related mortality is primarily documented for hatcheries and aquaculture facilities. Disease epizootics in wild salmon are uncommon in New England (Secombes 1991); furunculosis is the only documented source of mortality in wild Atlantic salmon (Bley 1987).

There are over 30 identified parasites of Atlantic salmon (Scott and Scott 1988). The most well known freshwater external parasites of Atlantic salmon are the gill maggot (*Salmincola salmonea*), the freshwater louse (*Argulus foliaceus*), and the leech (*Piscicola geometra*). Internal parasites include trematodes (flukes), cestodes (tapeworms), acanthocephalans (spiny-headed worms) and nematodes (round worms) (Jones 1959, Hoffman 1967, Mills 1971).

Although not detected in the U.S., *Gyrodactylus salaris* is an ectoparasite that has, in the last decade, resulted in serious problems for Atlantic salmon populations in Norway (Johnsen and Jensen 1991, Bakke et al. 1990). Håstein and Linstad (1991) report that this parasite is a major disease problem in Norwegian salmon rivers, and has caused almost total eradication of young salmonids in some rivers. Farmed fish are amenable to treatment. Bakke (1991) reports that *G. salaris* now occurs in Russia, Finland, Sweden

and Norway. There is evidence to suggest that susceptibility to *G. salaris* varies among stocks, and water temperature is an important variable with respect to reproduction and transmission of this parasite. In Norway the parasite is now reported in 34 rivers and about 35 hatcheries and its distribution in wild salmon populations is associated with the stocking of fish from infected hatcheries (Johnsen and Jensen 1991).

Once in the sea, Atlantic salmon lose their freshwater parasites but acquire others from the marine environment. The variety of parasites may increase for Atlantic salmon in the sea. For most ocean fishes the increase is related to the variable food source, the assortment of intermediate hosts found in the ocean, the vast area of migration which increases exposure, the tendency of fishes to school in the ocean during various life stages, and/or the increase in size of the host body (Polyanskii and Bykhovskii 1959).

The sea louse (*Lepeophtheirus salmonis*) is one of the more common ocean parasites of Atlantic salmon. At least one of three species of sea lice (*L. salmonis, Argulus Canadensis, Caligus elongata*) were observed on 189 of 2,045 returning adults on the Penobscot River in 1996 (Powell et al.1999). With severely infested fish, often the skin is loose and flesh may be exposed. In Norway, the level of sea lice infestation on wild fish in some areas where Atlantic salmon farming is concentrated, has been found to be 10 times greater than in areas where there are no farms (NASCO 1993). Sea lice have been suggested as vectors of disease, particularly of ISA (Nylund et al. 1994) as lice move from fish to fish and feed on fish tissue. Field studies were conducted at a clinical ISA site in Cobscook Bay that included testing for ISAv in fish and sea lice. ISAv positive sea lice were found at the infected site and were highly correlated with being on infected fish (Giray et al. 2004).

To reduce the potential for transmission and to improve the health of farmed salmon, the salmon aquaculture industry in Cobscook Bay has been participating in an Integrated Sea Lice Management Program, using emamectin benzoate under an Investigational New Animal Drug (INAD) permit. This drug has been demonstrated through field studies to be efficacious in significantly reducing the number of sea lice on farmed salmon (Stone et al. 2000).

The only known vertebrate parasite is the sea lamprey (*Petromyzon marinus*). The impacts of sea lamprey on Great Lakes fishes and introduced salmonine species are well documented, but few cases of lamprey parasitism are known for sea-run Atlantic salmon (Mills 1971, Kircheis 2004). Mature sea lampreys are anadromous and enter New England rivers in the spring, as they ascend rivers to spawn. However, they cease feeding upon freshwater entry (Kircheis 2004). Thus, even when attachment wounds are observed (e.g., Powell et al. 1999), it is unlikely that lampreys have been actively feeding on adult salmon.

Atlantic salmon are susceptible to numerous bacterial, viral, and fungal diseases. The more common bacterial diseases to New England waters include furunculosis, bacterial kidney disease (BKD), enteric redmouth disease (ERM), coldwater disease (CWD), and vibriosis (Mills 1971, Gaston 1988, Olafsen and Roberts 1993, Egusa 1992).

Furunculosis can be a problem in both the freshwater and marine life stages of Atlantic salmon. It is so widespread that no natural waters with resident fish populations are considered to be free of it. Because of the high incidence of this pathogen in some Atlantic salmon rivers in the U.S., many returning mature salmon carry it (Gaston 1988). Furunculosis can be treated in hatchery populations through the administration of antibacterial medicated feed and/or intraperitoneal (IP) injections. Control measures include commercial vaccines and surface disinfection of eggs with iodophore. Furunculosis can be a source of significant mortality in wild populations if river water temperatures become unusually high for extended periods.

Bacterial kidney disease is a chronic infection of salmonine fishes in culture environments. The bacterium is vertically transmissible even with egg disinfection measures, and once established, it can be difficult to control and virtually impossible to cure. Control in hatcheries depends on ensuring that eggs and smolts are from non-infected stocks; control in farms requires that fish be nutritionally fit (Olafsen and Roberts 1993, Gaston 1988, Egusa 1992). Although present in Canada as well as the US, there is not a high frequency of occurrence of BKD in the Northeast. Its occurrence in federal and most state trout hatcheries in New England has been limited. An added benefit of the ISAv management program in Cobscook Bay has been the near disappearance of BKD from Atlantic salmon farms (Stephen Ellis, USDA – APHIS, personal communication).

Enteric redmouth disease (ERM) is caused by the bacterium (*Yersinia ruckeri*). It occurs in salmonids throughout Canada and much of the U.S. and has been documented in cultured as well as captive sea-run Atlantic salmon in Maine and Connecticut (Gaston 1988). Generally this disease results in sustained low-level mortality, but large scale epizootics can occur if chronically infected fish are stressed during hauling, or exposed to other poor environmental conditions. This disease is amenable to treatment in hatcheries using medicated feeds or, for recaptured wild adults, intraperitoneal injections. Control in cultured populations is accomplished through commercially available vaccines and surface disinfection of eggs.

Bacterial Coldwater Disease, caused by *Flavobacterium psychrophilum*, has been identified as a potential problem to hatchery-reared Atlantic salmon. The bacterium is associated with poor egg quality, nervous system damage, and skeletal deformities in fry (Holt 1987, Cipriano et al. 1995). Although the organism is fairly well distributed in the environment, recent studies suggest that vertical transmission of *F. psychrophilum* via intra-ovum infection may have an affect on restoration efforts (Cipriano 2005). Recent changes in federal hatchery practices in Maine have greatly improved egg quality and survival; bacterial assays of eggs and fry prior to movement or stocking have not detected this pathogen.

Vibriosis occurs in many species and is likely ubiquitous in marine and estuarine waters. In infected salmonine species, red necrotic or boil-like lesions occur in the musculature. Hemorrhages may occur in the viscera and the intestinal track becomes inflamed. Typically, outbreaks and the level of severity escalate with an increase in water

temperature. There have been recent reports of cold water vibriosis infection in farmed Atlantic salmon in Norway and Scotland. The infection occurs during winter at water temperatures below 9°C, and resembles the condition referred to as "Hitra disease" in Norway (Gaston 1988). A commercially available vaccine is utilized extensively in the salmon aquaculture industry to reduce losses to Vibriosis.

Piscirickettsiosis is a disease of salmonids, including Atlantic salmon, caused by *Piscirickettsia salmonis*, a rickettsial-like, intracellular bacterium. The disease was first described in 1989 from farmed coho salmon (*Oncorhynchus kisutch*) in Chile (Bravo and Campos 1989) and has been reported also from salmon farms in Ireland, Norway, and the east and west coasts of Canada. *P. salmonis*-like organisms have been identified from non-salmonids. The relationship of these to *P. salmonis* has not been fully clarified, however the organism isolated from hatchery-reared white sea bass in California is genetically and serologically indistinguishable from *P. salmonis* (Chen et al. 2000). This is a chronic, systemic infection that affects all ages of salmonids principally in seawater. *P. salmonis* is very sensitive to antibiotic treatment and can easily be controlled in culture. This disease has not been diagnosed in the U.S.

Atlantic salmon exhibit a limited number of viral diseases in culture; common ones include infectious pancreatic necrosis (IPN) and salmon papilloma (Olafsen and Roberts 1993). IPN is endemic in New England and in the Canadian Maritime Provinces. The IPN virus has generally not been found to be a serious source of mortality in Atlantic salmon in North America but continues to cause serious mortality in cultured European stocks. Currently IPN is the major problem in Scotland with nearly 90% of the farms in some areas affected by this virus, and is a steadily increasing problem on Norwegian salmon farms. The disease cannot be treated effectively in the hatchery and avoidance is the most effective control mechanism. Salmon papilloma or pox is a benign condition that can occur on wild and farmed fish in the first or second year of life.

Infectious Salmon Anemia (ISA)/Hemorrhagic Kidney Syndrome (HKS) was found in Canadian (New Brunswick) net pen sites in the Bay of Fundy in 1996. This was the first occurrence of this virus in North America although it had been in Norway since 1984 and has subsequently been detected at a number of sites in Scotland and the Shetland Islands, the Faroe Islands, and Chile. The Scottish and Shetland outbreaks of ISA have been linked to a single primary source and the spread of the disease has been associated with farming practices and inter-farm transfers. A vaccine to prevent ISA outbreaks is on the market and several other vaccines are in development. Norway and Scotland have pursued a strategy of eliminating the disease by slaughter of infected fish, long-term fallowing of infected sites and, since effluent from processing plants and transport barges was identified as a high risk for spread of the disease, treatment of slaughter effluent. The strategy appears to have been successful in Scotland but outbreaks continue to occur in Norway. Known occurrences of the disease have been limited to aquaculture operations. Mortalities associated with ISA have been high in Canada and similar eradication management measures were initially adopted in response to the presence of the disease, including destroying infected fish, removing all fish from the infected zones and financial compensation to growers. More recently, Canada appears to have

moderated their strategy from eradication to containment (reduction or elimination of financially compensated destruction). The disease was detected in 1998 at two land-based facilities in Nova Scotia that have no obvious ties to the infected New Brunswick sites.

The first outbreak of ISA in the United States was reported in February of 2001 in one farm in Cobscook Bay, Maine. The second and third reported cases occurred within three and five weeks, respectively. Despite industry's efforts to control the spread of the disease through biosecurity measures and voluntary depopulation of infected cages, by early September, 11 of 17 active Cobscook Bay culture sites reported at least one diseased cage.

On September 10, 2001 MDMR put into effect an emergency rule which mandated (1) monthly testing for ISAv at sites within Cobscook Bay and quarterly testing for sites outside Cobscook Bay, (2) reporting of all test results to the MDMR, confirmed positive sites being subject to immediate remedial action, and (3) restrictions on the movement of aquaculture vessels and equipment out of or into Cobscook Bay. The industry voluntarily depopulated infected cages but new cases at previously diseased and uninfected sites continued to break out through November. By December of 2001 approximately 925,000 fish had been removed and the situation was not improving. These conditions led to a radical decision by MDMR, with assistance of the U.S. Department of Agriculture-Animal and Plant Health Inspection Service (USDA-APHIS), to immediately depopulate all cultured salmon in the bay, thoroughly clean and disinfect nets, cages and equipment, fallow all sites for over three months and start anew with staggered stocking between year classes at lowered stocking densities the following spring.

The ISA management plan, developed jointly between the industry and state/federal agencies to eradicate the disease from Cobscook Bay, met with early success. However, a year after repopulating cages in the bay, two farms were affected, each with detections of ISAv in single cages occurring in June 2003. These were followed by additional individual cage detections at these and other farms in Cobscook Bay in 2003, 2004, and 2005. Nearly all affected cages were voluntarily harvested, and those that were not, were depopulated and rendered. Continued outbreaks of ISA in the interconnected Cobscook Bay and Passamaquoddy Bay pointed to the need for further consideration of the Maine and New Brunswick ISA management plans. Cooperation between U.S. and Canada fish health professionals has led to a coordinated single bay management scheme for these bays, projected to be fully implemented in the spring of 2006.

All Atlantic salmon farm sites in Maine are mandated to participate in the ISA surveillance program. Until late 2003, ISAv was not detected outside Cobscook Bay. During routine surveillance monitoring, ISA virus was detected at one farm in November 2003 off Jonesport, Maine, approximately 60 miles southeast of Cobscook Bay. Although no signs of disease were present, frequency of monitoring was increased at the site, and over the course of a year, the detection prevalence increased, then decreased until there was no detection of ISAv. Since then, ISAv has remained undetected at this site using reverse transcription-polymerase chain reaction (RT-PCR), indirect fluorescent

antibody test (IFAT) specific for ISAv or by viral isolation methods. Over the period of 12 months clinical signs of disease were not observed and ISAv was not isolated from fish testing positive by RT-PCR or IFAT, suggesting this may be a non-pathogenic strain. Gene sequencing of the RT-PCR product indicates this virus is more closely related to pathogenic strains from Norway and Scotland. Sequencing of archived samples from the ISAv diseased Cobscook Bay sites is underway to determine the presence or absence of this second strain during the early outbreaks.

Recent environmental studies at a clinical ISA site detected ISAv in seawater up to 1.5 km away, and on surfaces of nets, boats and pontoons that were exposed to seawater (Giray et al. 2004), emphasizing the necessity of disinfecting boats, nets and other equipment at infected sites in order to restrict the spread of the pathogen.

In Canada, wild salmon captured from the Magaguadavic River and held for spawning developed ISA and died after nearly a month in captivity. The etiology was confirmed by strong RT-PCR reactions and viral isolations of ISAv. Although brackish water was used for holding the wild fish, the source of infection in the wild fish remains unknown (Gilles Olivier, DFO Canada, personal communication). In 1998, the USFWS began monitoring all captured sea run salmon mortalities, ovarian fluids, and annual, post spawning statistically-based (60) lethal samplings for ISA virus and it has not been detected from these tissues. Since 2001, all Penobscot River sea run salmon held in captivity for spawning (usually around 600 per year) also are sampled non-lethally (blood) for ISA virus prior to spawning by both RT-PCR (molecular testing) and cell culture. Although no ISA virus positive results have been obtained in the last three years, in 2001, one fish did produce a positive result from the PCR test. Repeat testing by PCR and cell culture by two laboratories, were subsequently unable to produce positive findings. Additionally, the gene sequence from the first testing showed 93% homology with the European strain, demonstrating this was not the North American strain which had been infecting net pens in Canada and Maine. In 2004, the captive sea run salmon from the Connecticut (n=61) and Merrimack (120) rivers were also non-lethally screened by RT-PCR and cell culture and no positive results were found.

Atlantic salmon in the Greenland commercial fishery, sampled to estimate the level of marine mortality in North American salmon stocks attributable to fishing, provided an opportunity for pathogen testing of the West Greenland stock. Tissues of 19 Atlantic salmon caught commercially and landed in Nuuk in 2001 were taken for viral culture, IFAT and RT-PCR assays for ISAv. For one fish, the PCR test gave a weak positive band for ISAv while the other assays were negative. Sequencing of the PCR product showed closest similarity to the first North American strain of the virus. Genetic analysis determined this fish was of North American origin. No RT-PCR positive test results were obtained from tissues of 267 Atlantic salmon collected in Nuuk in 2003, 2004, and 2005 (NOAA, unpublished data).

Studies of wild fishes, including non-salmonids, were initiated in Canada and the U.S. in attempts to identify potential reservoirs of the ISA virus. In the U.S. 4,900 fish of various species have been tested for ISAv by RT-PCR and viral isolation methods. ISAv was

detected by RT-PCR in one of 120 alewife collected from the Narraguagus River in Maine in 2003. Genetic sequencing of the RT-PCR product showed 99 to 100% homology with the North American strain of ISAv. Two of 16 pollock taken from inside ISA-diseased cages were weakly RT-PCR positive and one of 24 pools (5 fish per pool) of tissues from 120 cod collected from the well-boat of a harvested clinically diseased cage produced a pathologic effect in the viral isolation assay. Similarly, the Canadian survey conducted since 1998 has demonstrated rather few RT-PCR positive results from wild salmon and that were not confirmed by isolation of ISAv (Giles Olivier, DFO Canada, personal communication). These results suggest the potential for various wild fishes to serve as reservoirs of ISAv; however, results of the broad surveys indicate that ISAv may be present at a very low prevalence in wild fish populations.

In 1998, a lethal retrovirus was detected in wild Atlantic salmon that had been captured as parr in the Pleasant River and reared at the North Attleboro National Fish Hatchery (NANFH) in Massachusetts. In 1995 (180 parr), 1996 (80 parr) and 1997 (164 parr) were held in isolation at the NANFH and a private hatchery in Deblois, Maine, for the purposes of rearing the fish to sexual maturity, spawning them, and returning progeny back to the Pleasant River. Mortalities began in two of three rearing units holding these salmon at North Attleboro in 1997 and continued in 1998; salmon in the third unit were never found to contain the virus or exhibit symptoms. Necropsy revealed massive tumors in the swimbladder. Pleasant River fish at Deblois were also found to be positive for the virus, though no disease was present and no mortality occurred. Cornell University scientists identified the causative agent as a cancer-causing retrovirus known as Salmon Swimbladder Sarcoma Virus. This disease and a presumptively causative retrovirus were first reported from sub-adult farmed Atlantic salmon in Scotland (Duncan 1978, McKnight 1978) and it was named Salmon Swimbladder Sarcoma Virus (SSSV) by Wolf (1988). In Norway swim bladder tumors, histologically resembling the salmon swim bladder sarcoma, were observed in three of 65 wild salmon in Norway collected as brood fish in 2000 and 2001 (Skjelstad et al. 2002). These were the first observations of this disease in Norway. The disease has not been reported from Scotland or Norway since, and the relationship between this and the Maine retrovirus has not been determined.

SSSV-positive fish from North Attleboro were moved to a quarantine facility at the USGS-Biological Resources Division facility in Leetown, West Virginia, to obtain detailed information on the pathogenicity of the virus, and the remaining stocks at North Attleboro and Deblois hatchery were destroyed. A non-lethal test for detection of this virus was developed by Cornell and testing of archived samples and wild salmon stocks from other Maine rivers held at the Craig Brook National Fish Hatchery in Maine was carried out. Of 1,598 salmon of various ages from seven rivers, 18 (7 parr and 11 pre-spawners) were found to be carriers of SSSV. These infected fish came from six rivers; Machias, East Machias, Pleasant, Narraguagus, Penobscot and Sheepscot. Samples from the Dennys River were negative for the virus. No fish at Craig Brook NFH has ever demonstrated symptoms of the disease in the twelve years wild stock have been held at that hatchery. However, the virus has demonstrated that it can cause lethal disease in salmon under the conditions existing in the Massachusetts hatchery. Results of this preliminary testing of captive Downeast Rivers wild stocks at CBNFH exhibiting no

signs of disease indicate that the virus may be widespread at a low level in the environment. Expressions of the disease such as observed at North Attleboro may only occur under extremely adverse environmental and/or nutritional conditions.

A togavirus isolated in tissue culture has been detected in Atlantic salmon from farms in Maine and New Brunswick. The virus appears to be in New Brunswick and has been found in the Cobscook Bay area of eastern Maine. There has been no disease found associated with this virus at present, but it is monitored as part of the routine health inspection process for aquaculture operations in Maine.

Heart and skeletal muscle inflammation (HSMI) in Atlantic salmon is a serious disease affecting farms on the west coast of Norway. The virus disease has a relatively high prevalence in the county of Møre and Romsdal, and extends from the southern tip of Norway to the Polar Circle. This disease was first reported in 1999 by fish health biologists at the National Veterinary Institute in Oslo and has become an increasing problem. In 2003 there were 68 outbreaks of HSMI, an increase from 41 sites reported in 2002. Typical mortality rates have been 5 to 10% over two months, although mortalities up to 20% and outbreaks as long as six months have occurred. The causative virus is as yet unidentified and vaccine development is underway. HSMI is known only from cultured fish in Norway.

Most salmon encounter fungi during their various life stages. Saprolegnia is the only fungal disease of Atlantic salmon and is primarily found in adult males. It invades the epidermis and is associated with the presence of high levels of androsteroids (Olafsen and Roberts 1993, Gaston 1988).

Clearly, a wide array of parasites and diseases could potentially affect the GOM DPS. Captive fish have the highest risks for disease transmission although a rigorous testing program for each conservation hatchery screens for a wide array of the most virulent pathogens. In addition, fish that must pass near aquaculture facilities are more likely to encounter both parasites and pathogens. However, substantial progress has been made in the last several years to reduce the risks to wild fish.

8.3.3 Competition

8.3.3.1 Production of juveniles in freshwater

Interspecific competition for food and habitat has been widely studied in many fish species including Atlantic salmon. In order for interspecific competition to limit population growth, two or more species must seek the same resource that is in short supply (Smith 1996); therefore, species that require similar resources are most likely to compete with one another (Case and Taper 2000). With Atlantic salmon, food and habitat are often considered limiting resources (Hearn 1987, Fausch 1988) though little quantitative information exists documenting the extent or severity of interspecific competition (Fausch 1998).

Prior to 1800, the resident riverine fish communities in Maine were relatively simple consisting of brook trout, cusk, white sucker, and a number of minnow species. Today, Atlantic salmon co-exist with a diverse array of non-native resident fishes including landlocked salmon, brown trout, largemouth bass, smallmouth bass, chain pickerel, and northern pike (MDIFW 2002). The range expansion of non-native fishes is important given evidence that niche shifts may follow the addition or removal of other competing species (Fausch 1998). For example in Newfoundland, Canada, where fish communities are simple, Atlantic salmon inhabit pools and lakes which are generally considered atypical habitats in systems where there are more complex fish communities (Gibson 1993). Use of lacustrine habitat in particular, can increase smolt production (Matthews et al. 1997). Conversely, if salmon are excluded from these habitats through competitive interactions, smolt production may suffer (Ryan 1993). Even if salmon are not completely excluded from a given habitat type, they may select different, presumably sub-optimal, habitats in the presence of certain competitors (Fausch 1998). Thus, competitive interactions may limit Atlantic salmon production through niche constriction (Hearn 1987).

Competition for food and habitat with each competitor can be measured individually; however, sufficient quantitative information is not yet available for most competitive interactions of interest. Often, only indirect signals of competition (e.g., shifts in habitat use) are apparent when examining species interactions. Examining the cumulative effects of competition is even more difficult and may in fact be impossible given the current lack of data (Fausch 1998). However, one trend is clear. Atlantic salmon in any given river must share the same amount of space with increasing numbers of competitors. Furthermore, if baseline productivity of aquatic ecosystems in Maine has declined because of diminished deposition of marine derived nutrients (see Section 3.3), then the amount of food available to the fish community as a whole has concomitantly been reduced. Thus, Atlantic salmon must share fewer resources with more competitors. It is impossible to quantitatively predict the effects of competition at this time; however, juvenile production of the GOM DPS is likely limited by competition for food and habitat.

The four species that likely compete with the GOM DPS of Atlantic salmon the most are brook trout, landlocked salmon, smallmouth bass, and brown trout. In addition, American eel and fallfish are two native fish that may compete with juvenile Atlantic salmon; though little is known about the competitive interactions among these species. Rainbow trout would be important competitors if their range overlapped more substantially. At this time, rainbow trout occur in at least three reaches of the Kennebec River and in the Androscoggin River. Stocking programs and illegal introductions continue to slowly expand their range (Pellerin 2002). Atlantic salmon and rainbow trout juveniles require similar resources; therefore, competition is expected to be considerable in areas where they co-occur.

Brook Trout

Brook trout and the GOM DPS of Atlantic salmon co-evolved. Therefore, these species are expected to have developed ways to minimize competitive interactions. Differential

habitat use in juvenile Atlantic salmon and brook tout is one way these species limit competitive interactions among individuals. During most of the growing season, juvenile Atlantic salmon use riffles while brook trout use pools (Gibson 1973, Gibson 1978). Although this mechanism may limit competitive interactions between these two species, juvenile Atlantic salmon growth may be suppressed by brook trout when they co-exist (Gibson and Dickson 1984, MASC and MDIFW 2002).

Landlocked salmon

Within the range of the GOM DPS, landlocked salmon were only native to the Sebec River subdrainage and the Union River drainage (Warner and Havey 1985). The extent of competitive interactions and gene flow among these ecotypes prior to European settlement is unknown. However, landlocked salmon (West Grand and Sebago strains) have been stocked throughout Maine and are routinely stocked in lakes in order to sustain sport fisheries (MDIFW 2002). Generally, these fish pose little threat to anadromous Atlantic salmon because landlocked salmon are stocked as fingerlings in lakes where they grow to adulthood feeding primarily on landlocked rainbow smelt (Warner and Havey 1985). However, there are some areas (e.g., East Branch Penobscot River) where landlocked salmon successfully spawn and rear in sympatry with anadromous Atlantic salmon. For these populations, competitive interactions for food and habitat are expected to be very high given the nearly identical early life history requirements of the two ecotypes. The BRT is not aware of any studies underway or planned that would examine the ecological interactions of sympatric landlocked and anadromous salmon.

Smallmouth bass

Smallmouth bass are not native to Maine. However, the range of smallmouth bass now extends through central and northern Maine well into New Brunswick (Jackson 2002, Warner 2005). Smallmouth bass are well adapted to both lacustrine and riverine environments and feed on many species arthropods and fish. Smallmouth bass are extremely common in many lakes as well as main stem habitats of the larger rivers in Maine, inhabiting many of the same areas used by juvenile Atlantic salmon. The thermal preference for smallmouth bass ranges from 20° to 28°C over much of its current distribution (Scott and Crossman 1973). Conversely, the peak feeding activity for juvenile Atlantic salmon occurs between 16 and 19°C with feeding generally stopping around 22°C (Elliott 1991). Thus, Atlantic salmon appear to have a competitive advantage at colder temperatures while smallmouth bass likely have a competitive advantage at warmer temperatures. The temperature of many rivers within the range of the GOM DPS often exceed 20° C by mid June and remain above 20°C until early September (NOAA unpublished data). Thus, smallmouth bass are likely strong competitors during a substantial portion of the growing season.

Brown trout

Although brown trout and Atlantic salmon co-evolved in parts of Europe, brown trout are not native to Maine yet have been stocked extensively. At present, brown trout are common in the Androscoggin, Kennebec, and Piscataquis Rivers as well as many lakes and ponds (Boland 2001, MDIFW 2002). Atlantic salmon and brown trout require fairly

similar resources to complete their life histories; therefore, competition is expected to be considerable in areas where they co-occur.

With juveniles, competitive interactions are largely driven by individual choices of habitat types as they seek to maximize food intake and simultaneously minimize predation risk (Metcalfe et al. 1999). Most evidence suggests that brown trout will displace or otherwise outcompete Atlantic salmon from pool habitats in both summer (Kennedy and Strange 1986) and winter (Harwood et al. 2001). The exclusion of parr from certain habitat types would presumably lead to emigration of individuals as they search for new territories. Thus, competition for habitat may ultimately reduce smolt production because experiments with some salmonid species have shown that those individuals introduced to a new location experience higher mortality rates than resident fish (Noakes 1978), perhaps because of risk associated with moving to unfamiliar areas (Dolloff 1987). Further, emigration from a profitable territory is more likely as competition increases as emigrants are generally smaller and in poorer condition than non-emigrants (Keeley 2001). Competition among Atlantic salmon and brown trout in winter may also diminish smolt production since availability of winter habitat (i.e., pools) often plays a critical role in the number of salmonids a stream can support (Cunjak 1996, Whalen and Parrish 1999), and predation rates are likely increased as salmon are forced to use sub-optimal habitats and change diel behavior patterns in the presence of brown trout (Metcalfe et al. 1999, Harwood et al. 2001). Gibson and Cunjak (1986) suggest that any competition between salmon and brown trout is minimal especially if riffle habitat is abundant; however, most evidence suggests that the presence of brown trout clearly leads to changes in habitat use and/or behavior in Atlantic salmon (Bremset 2000). In some instances, this may limit salmon production through niche constriction when the two species co-occur (Hearn 1987, Fausch 1988).

Brown trout and Atlantic salmon also demonstrate similar spawning site preferences and spawn at about the same time in the fall. Evidence also suggests that brown trout females may prefer to spawn on existing redd sites. This creates the potential for superimposition of redds in spawning areas (MASC and MDIFW 2002).

Brown trout are capable of hybridizing with other salmonids (Brown 1966, Dangel et al. 1973, Chevassus 1979, Taylor et al. 1984, Beall et al. 1997). Studies in Sweden (Nilsson 1965), Scotland (Hearn 1987), and Canada (Beland et al. 1981, Beall et al. 1997) have documented brown trout/Atlantic salmon hybrids. One study that examined the incidence of hybrids in salmonid populations in Northern Spain and Southwestern France determined that significant proportions of salmonid populations were locally affected by hybridization. Hybridization was found to occur in the absence of conspecific males and due to the modification of spawning behavior by females (Beall et al. 1997). Hybridization has also been observed in the Connecticut River where salmon fry were stocked into a headwater tributary, where no adult salmon were present. The stream had a self-sustaining population of brown trout and enzyme electrophoresis later demonstrated the presence of one hybrid. Given that the maternal species was identified as a brown trout, Gephard et al. (2000) concluded that the male parent had to have been a

precocious male Atlantic salmon parr. Evidence also suggests that the number of hybrids increases with increasing population densities (MASC and MDIFW 2002).

Many of these putative relationships are based on investigations conducted at the individual rather than the population scale. Although additional research would be required to elucidate the extent of these interactions at the population scale (Fausch 1998), it appears that competitive interactions between salmon and brown trout are likely quite high particularly among juveniles in rivers with abundant pools.

8.3.3.2 Competition among hatchery reared and wild salmon

Competition among hatchery reared and wild Atlantic salmon is not well researched. Competition could occur between wild and hatchery juveniles (i.e., competition for food and space) or between wild and hatchery adults (i.e., competition for redd sites). To minimize competitive interactions that may occur between juveniles, fry are stocked at least 50 m from any known redd. At this time, competition for redd sites between wild and hatchery reared salmon appears to be minimal. In short, there are substantial amounts of accessible yet unused spawning habitat throughout the range of the GOM DPS. Thus, this resource can not be limiting since it is not in short supply; although the quality of spawning habitat may have been diminished through past land use practices (see Section 8.1 for a detailed review).

8.4 Inadequacy of Existing Regulatory Mechanisms

8.4.1 International, National and State Laws, Treaties and Agreements

A number of state and federal laws have the ability to affect the abundance and survival of Atlantic salmon in the northeast United States. Measures taken on the international, national, and state levels to restrict the harvest of U.S. origin Atlantic salmon are discussed in Section 8.2 and consequently will not be repeated in this section. Despite their breadth, these laws have not prevented or reversed the observed declines in salmon stocks. Regulations that are either inadequate or not being enforced are summarized in Section 8.4.5.

8.4.1.1 Endangered Species Act

The Endangered Species Act (ESA) was enacted in 1973 to protect species that are threatened or endangered and to prevent the destruction or curtailment of habitat critical to the conservation of the species. The Services determine whether a species should be listed after conducting a formal Status Review. In addition to the information presented in the Status Review, the Services must consider specific factors and on-going conservation efforts in order to make their determination as to whether a species warrants listing. Once a species is listed as endangered, section nine of the ESA prohibits the take of listed species. Any or all of these prohibitions can be applied to threatened species. Take is defined as to harm, harass, pursue, hunt, shoot, wound, trap, kill, capture or

collect a listed species. Pursuant to section 7(a)(2) of the ESA, Federal agencies are required to consult with the Services on all federal actions to determine the potential effects of their activities on protected species. If a federal action is likely to adversely affect a listed species, then the Services work with the action agency to find ways to avoid, minimize, or mitigate adverse effects during the section seven consultation process. In addition, section 7(a)(1) requires all federal agencies to utilize their authorities carry out programs for the conservation of endangered and threatened species as well. The Services may also review non-federal activities that may take listed species and issue permits under section 10 for the incidental take of a listed species and for scientific research and enhancement purposes.

In 1999, the Services conducted a Status Review on Maine Atlantic salmon. This Status Review revealed that there were remnant populations of wild Atlantic salmon in Maine that were in danger of extinction throughout all or a significant portion of their range. On November 17, 2000, the Services jointly listed the GOM DPS of Atlantic salmon as endangered under the ESA. The GOM DPS as listed in 2000, included all remnant populations of wild Atlantic salmon from the mouth of the St. Croix to the former site of the Edwards Dam on the Kennebec River, excluding the Penobscot above the former site of the Bangor Dam. Within this range, the Services identified remnant populations in the Sheepscot, Ducktrap, Narraguagus, Pleasant, Machias, East Machias, and Dennys Rivers and Cove Brook. Since the listing, the Services have been conducting section seven consultations on all federal actions within the range of the GOM DPS (as listed in 2000) that have the potential to adversely affect Atlantic salmon. In addition, section nine has resulted in prohibitions on all take of Atlantic salmon within the range of the GOM DPS (as listed in 2000). Although the GOM DPS (as defined in the 2000 listing) remains protected under the ESA, the rest of this section discusses the adequacy of other regulatory mechanisms to inform the decision as to whether the newly delineated DPS (see section 6 of this report) warrants ESA listing.

8.4.1.2 Convention for the Conservation of Salmon in the North Atlantic Ocean

This treaty, ratified by the U.S. in 1982, provides a mechanism for managing the international commercial fishery for Atlantic salmon for the purpose of conserving and restoring salmon stocks. The Convention provides a forum for coordination among members, proposing regulatory measures, and for making recommendations regarding scientific research. The Treaty was adopted by the U.S., Canada, Greenland (as represented by Denmark), Iceland, Faroes Islands, Norway, and the E.C. Russia joined later. The North Atlantic Salmon Conservation Organization (NASCO) was formed by this treaty.

The U.S. became a charter member of NASCO in 1984. NASCO is charged with the international management of Atlantic salmon stocks on the high seas. The NASCO is composed of three geographic Commissions: Northeast Atlantic, West Greenland, and North American. Each signatory appoints three Commissioners, and the three Commissioners sit on the Commissions that impact the salmon from their area. NASCO seeks scientific advice from the International Council for the Exploration of the Seas (ICES). The three U.S. Commissioners are appointed by the President and function

under the auspices of the U.S. State Department. The U.S. Commissioners seek advice and input from scientists involved in Atlantic salmon research and management throughout New England, which comprise the U.S. Atlantic Salmon Assessment Committee (USASAC). The USASAC was formed by the Federal and New England state fishery agencies for this purpose.

8.4.1.3 Convention for the International Council for the Exploration of the Sea (ICES) (24 U.S.A. 1080; T.I.A.S. 7628)

The Convention was established in 1973 to (1) promote and encourage research and investigations for the study of the sea, particularly those related to the living resources thereof; (2) draw upon programs required for this purpose and to organize such research and investigations as may appear necessary; and (3) publish or otherwise disseminate the results. ICES is the official research arm of NASCO and is responsible for providing scientific advice to be used by NASCO members as a basis for formulating biologically sound management recommendations for the conservation of North Atlantic salmon stocks. ICES delegates responsibilities for the collection and analysis of scientific data on Atlantic salmon to the North Atlantic Salmon Scientific Working Group, which is then used by the ICES Advisory Committee for Fishery Management to formulate advice to NASCO annually.

8.4.1.4 Fishery Conservation and Management Act of 1976, (16 U.S.C. 1801 et seq.)

This Act, commonly referred to as the "Magnuson Act," gives regional fishery management councils the authority to prepare plans for the conservation and management of each federally managed fishery in the EEZ, including the establishment of necessary habitat conservation measures. As discussed in Section 8.2, a fishery management plan for Atlantic salmon was implemented by the New England Fishery Management Council (NEFMC) and the Assistant Administrator for Fisheries in 1987.

The 1996 amendments to the Magnuson-Stevens Fishery Management and Conservation Act set forth a number of new mandates for the NMFS, regional fishery management councils, and other federal agencies to identify and protect important anadromous fish habitat (16 U.S.C. 1855(b)). The fishery management councils, with assistance from NMFS, are required to delineate essential fish habitat (EFH) for all managed species. Federal action agencies which fund, permit or carry out activities that may adversely impact EFH are required to consult with NMFS regarding the potential effects of their actions on EFH, and respond in writing to the NMFS' recommendations. In addition, NMFS is required to comment on any state agency activities that would impact EFH.

The NEFMC promulgated a fishery management plan for Atlantic salmon in 1987. In accordance with the 1996 amendments, the NEFMC designated EFH for Atlantic salmon in March of 1999. EFH is defined in the Magnuson-Stevens Act as those waters and substrate necessary to fish for spawning, breeding, feeding, or growth to maturity. As required by the Magnuson-Stevens Act, NMFS promulgated regulations to provide guidance to the Councils for EFH designations. The regulations further clarify EFH by defining waters to include aquatic areas and their associated physical, chemical, and

biological properties that are used by fish and may include aquatic areas historically used by fish where appropriate; substrate to include sediment, hard bottom, structures underlying the waters, and associated biological communities; necessary to mean the habitat required to support a sustainable fishery and the managed species contribution to a healthy ecosystem; and spawning, breeding, feeding, or growth to maturity to cover a species full life cycle.

Essential fish habitat for Atlantic salmon is described as all waters currently or historically accessible to Atlantic salmon within the streams, rivers, lakes, ponds, wetlands, and other water bodies of Maine, New Hampshire, Vermont, Massachusetts, Rhode Island and Connecticut and that meet conditions for eggs, larvae, juveniles, adults and/or spawning adults. Atlantic salmon EFH for eggs, larvae, juveniles and adults includes all aquatic habitats in the watersheds of rivers where salmon are currently present (26 rivers total), including all tributaries, to the extent that they are currently or were historically accessible for salmon migration. In conjunction with the NEFMC, NMFS is currently conducting a five year review for any new information that has been released since 1999 in order to refine the existing EFH designation for Atlantic salmon.

The regulations also direct the Councils to consider a second, more limited habitat designation, Habitat Areas of Particular Concern (HAPCs). HAPCs are rare, particularly susceptible to human-induced degradation, especially ecologically important, or located in an environmentally stressed area. Designated HAPCs are not afforded any additional regulatory protection under the Magnuson-Stevens Act; however, federal projects with potential adverse impacts to HAPCs will be more carefully scrutinized during the consultation process. Considering the unique habitat associations and requirements of Atlantic salmon, the Council designated the habitat of 11 rivers in Maine as HAPCs for Atlantic salmon in March 1999. The habitat of the Dennys, Machias, East Machias, Pleasant, Narraguagus, Ducktrap, Sheepscot, Kennebec, Penobscot, St. Croix Rivers and Tunk Stream was identified as serving the following two important purposes in terms of being habitat areas of particular concern: (1) they provide a unique and important ecological function; and (2) they are sensitive to human-induced environmental degradation.

NMFS has committed to attempt to incorporate EFH consultations into interagency procedures previously established under the National Environmental Policy Act, Endangered Species Act, Clean Water Act, Fish and Wildlife Act, or other applicable statutes. Once the NMFS learns of a federal or state project that may have an adverse effect on EFH, NMFS is required to develop EFH Conservation Recommendations for the project. These recommendations may include measures to avoid, minimize, mitigate, or otherwise offset adverse effects on EFH. Federal agencies are required to respond to EFH Conservation Recommendations in writing within 30 days. Councils are also authorized to comment on federal and state projects and are required to comment on any project that may substantially impact anadromous fish habitat. Federal action agencies are required to prepare an EFH Assessment which must include the following: (1) a description of the proposed action; (2) an analysis of the effects, including cumulative effects of the actions on EFH, the managed species, and associated species by life history

stage; (3) the federal agency's views regarding the effects of the action on EFH; and (4) proposed mitigation, if applicable.

8.4.1.5 The Maine Indian Land Claims Settlement Act

Native American Tribes are recognized by the United States Government as domestic dependent nations under its protection. Indian tribes exercise sovereign authority over Indian territories and members. The domestic dependent status of Indian Tribes has created a unique relationship between the United States and Tribal Governments, also referred to as the "federal trust" responsibility. The federal trust responsibility is defined as: The United States Trust responsibility toward American Indians is the unique legal and fiduciary duty of the United States to assist Indians in the protection of their property and rights.

In the face of growing disputes over land claims between the State of Maine and the tribes, the tribes began to pursue land claims in Maine in the early 1970s. The tribes originally began to pursue land claims in Maine to acquire close to 2/3rds of the land within the State of Maine. The State of Maine challenged the tribes and it was not until years later that the State and the Tribes were able to negotiate a settlement of the land claims. This resulted in the Maine Indian Land Claims Settlement Act (The Settlement Act), October 10, 1980 (Title 30 Chp 601).

The Settlement Act represents the only congressionally ratified statement of the relationship between the Penobscot Indian Nation (PIN) and the United States Government, given that the PIN had no prior agreements with the United States. In Passamaquoddy v. Morton 388 F. Supp. 649 (D. ME 1975), aff'd 528 F. 2d 370 (1st Cir. 1975) the federal trust relationship between the PIN and the United States was declared. The trust relationship between the U.S. and PIN was never expressly terminated by Congress in the Settlement Act (25 USC 1721 et. seq.). In addition, most of the lands, and the natural resources attached to those lands, that were acquired by the PIN as a result of the Settlement Act were acquired by DOI "in trust" for the tribes (25 USC 1722(b)). The United States Government defines "lands and natural resources" held in trust to include "water and water rights, and hunting and fishing rights" of the PIN (25 USC 1724(d)).

Atlantic salmon are and always have been an integral part of the history of the PIN. The species represents both an important resource for food, and perhaps more importantly, a cultural symbol of the deeply engrained connection between the PIN and the Penobscot River. In accordance with the Settlement Act, the Penobscot Indian Nation retains the right of its members to harvest Atlantic salmon for subsistence and sustenance purposes, and to self-regulate that harvest. While it could potentially decide to exercise this right at any time in the future, the PIN has harvested a total of only two salmon under these provisions, and has voluntarily decided not to harvest any Atlantic salmon since 1988, due to the status of the species in its territorial waters.

8.4.1.6 The Maine Atlantic Salmon Commission

The MASC was formed by the Maine Legislature in June of 1999, replacing the Atlantic Salmon Authority. The MASC consists of three members appointed by the Governor: Commissioner of MDIFW; Commissioner of MDMR; and one At-Large public member. The Commission appoints an executive director for a five year term. The MASC, like its predecessors the Atlantic Salmon Authority and the Atlantic Sea Run Salmon Commission, is granted sole authority and responsibility to manage the Atlantic salmon fishery in the state.

8.4.1.7 Cooperative Agreement: USFWS, NMFS and the ASA

The USFWS and Maine had an agreement initiated on May 9, 1962, and renewed through 1997 to create a program of Atlantic salmon hatchery production and stocking for the purpose of furthering restoration of Atlantic salmon in the state of Maine. To assist in technical matters and marshal scientific expertise for addressing appropriate research, the Maine Technical Advisory Committee (TAC) was established as part of the Agreement. The USFWS, NMFS, and ASA entered into a Cooperative Agreement effective January 1, 1998, through December 31, 2003, to further their common goal of protecting and recovering Atlantic salmon in Maine. The Cooperative Agreement has not been renewed and the TAC is currently operating under the expired Agreement. The Cooperative Agreement maintains the TAC for the purpose of advising the Parties on any technical matter relative to the Atlantic salmon restoration and rehabilitation programs in Maine, pledges cooperation in activities to implement the Conservation Plan, continues USFWS' commitment to the river-specific stocking program, and contains an agreement to cooperate on salmon population and habitat inventories, management investigations, and other activities of shared concern.

8.4.1.8 Cooperative Agreement: NMFS and the Maine Atlantic Sea Run Salmon Commission

This Agreement was created in 1990 to address research issues of concern relative to the rivers of eastern Maine that have predominately wild Atlantic salmon populations. This Agreement has steadily risen to current levels well over one million dollars annually. This funding allows the MASC to enumerate adult returns on several rivers, assess juvenile abundance, conduct habitat surveys, and conduct various other projects in support of Atlantic salmon conservation in Maine.

8.4.1.9 Fish and Wildlife Coordination Act (6 U.S.C. 661-66; 48 Stat. 401), as amended

Under this Act the federal regulatory and construction agencies must give consideration to fish and wildlife resources in their project planning and in the review of applications for federal permits and licenses. These agencies must consult with state and federal fish and wildlife agencies regarding the possible impacts of proposed actions and obtain recommendations for fish and wildlife protection and enhancement measures. The USFWS and the NMFS provide recommendations to federal action agencies that include measures to protect fish and wildlife resources. The FWCA consultation requirement applies to water-related activities for which federal permits are required, the most significant of which are Section 404 and discharge permits under the Clean Water Act,

and Section 10 permits under the River and Harbors Act. Agency recommendations are to be given full consideration by the permitting agency, but are not binding.

8.4.1.10 Federal Power Act (16 U.S.C. 791a-8254; 41 Stat. 1063), as amended

This act, as amended, established several processes intended to protect and restore anadromous fishes impacted by hydroelectric facilities regulated by the Federal Power Commission and its successor agency, the Federal Energy Regulatory Commission (FERC). The Electric Consumers Protection Act (ECPA) of 1986 strengthened the position of the fish and wildlife agencies and Indian Tribes by requiring FERC to include conditions in licenses to protect, mitigate, and enhance fish and wildlife resources. Section 18 of the Act assigns to the Commission a responsibility to require hydroelectric licensees to construct, maintain, and operate at their expense fishways prescribed by the Secretaries of Interior or Commerce; however, the resultant changes to sections 10(a) and 10(j) of the Federal Power Act are largely discretionary and not mandatory. In addition, Section 4(e) of the Federal Power Act (as amended by the ECPA) establishes that FERC must give equal consideration to developmental and non-developmental values in its licensing decisions for projects located on federal reservations. Thus, FERC is responsible for assessing the power and "non-power" values associated with these different alternatives to determine which option would give the greatest benefit to the public; however, the non-power benefits of re-licensing alternatives are rarely quantified or incorporated in net benefit estimates (Black et al. 1998).

The Penobscot River Restoration Project (PRRP) is the result of many years of negotiations between Pennsylvania Power and Light (PPL), U.S. Department of the Interior (i.e., USFWS, Bureau of Indian Affairs, National Park Service), Penobscot Indian Nation, the state of Maine (i.e., Maine State Planning Office, MASC, Inland Fisheries and Wildlife, Department of Marine Resources), and several non-governmental organizations (NGO's) (Atlantic Salmon Federation, American Rivers, Trout Unlimited, Natural Resources Council of Maine, among others). If implemented, the PRRP would lead to the removal of the two lowermost main stem dams on the Penobscot River (Veazie and Great Works) and would decommission and construct a nature-like fishway around a third dam (Howland Dam). This initiative will vastly improve habitat accessibility for all diadromous species. For example, less than 7% of post-project salmon habitat will be above four or more dams, and at least 43% of the habitat would require, at most, one dam passage in each direction with conventional passage facilities. At least 15% of salmon habitat would have no intervening dams remaining, compared to 2.5% presently (see section 8.1). In June of 2004, the Parties to the negotiations signed the Penobscot Multiparty Settlement Agreement (MPA). The MPA includes a 5-year option period during which time the "Penobscot River Restoration Trust" has the opportunity to raise the necessary funds, estimated at 25 million dollars for the purchase of the dams and another 25 million dollars for decommissioning and removal. If the purchase and removal option is not exercised, fishway prescriptions issued by the Services will be implemented.

8.4.1.11 Federal Water Pollution Control Act Amendments of 1972 (33 U.S.C. 1251-1376)

Pursuant to section 402 of the Federal Water Pollution Control Act (Clean Water Act [CWA]) the National Pollutant Discharge Elimination System (NPDES) permit program controls water pollution by regulating point source discharges into water bodies within the U.S. Facilities that discharge directly into water bodies must obtain a NPDES permit. In most cases the Environmental Protection Agency (EPA) authorizes States to administer the NPDES permit program. On October 13, 1999, the state of Maine requested NPDES program approval from the EPA. In 2001, the EPA authorized the State of Maine to administer the NPDES program after concluding formal consultation during which the Services determined that authorization would not jeopardize the GOM DPS of Atlantic salmon (as listed in 2000). The Services and EPA also outlined procedures for reviewing the terms of proposed permits for Atlantic salmon aquaculture or hatchery facilities during formal consultation. Pursuant to existing CWA regulatory authority requirements and the Memorandum of Agreement between the EPA and the state of Maine, the Department of Environmental Protection (DEP) for the State of Maine must provide notice and copies of draft permits to the Services. The Services then have 30 or 90 days depending on the type of permit to submit comments to DEP. The Services currently review and submit comments to DEP on all NPDES permits that may affect the GOM DPS, as listed in 2000.

Under the NPDES permit program, the state of Maine is responsible for issuing permits for point source discharges including discharges from marine aquaculture facilities and freshwater hatcheries, municipal facilities, and other industrial facilities. The NPDES permits issued by the State also place limits on the amount of pollutants discharged and impose other conditions such as monitoring and best management practices in order to protect water quality. The EPA retains oversight authority over NPDES permits issued by Maine, including the authority to object to a permit where among other reasons EPA finds that the permit does not ensure compliance with EPA regulations or applicable water quality standards under the CWA.

Section 404 of the CWA also provides for the Corps of Engineers to issue permits for the discharge of dredge or fill materials into navigable waters. Permit applications must be reviewed by the USFWS and the NMFS for impacts on fish and wildlife.

8.4.1.12 Fish and Wildlife Act of 1956 (16 U.S.C. 742a-742j; 70 Stat. 1119), as amended

Section 7(a), among other things, authorizes the Secretary of Interior to initiate measures required for the development, enhancement, management, conservation, and protection of fishery resources.

8.4.1.13 Federal Aid in Fish Restoration Act (16 U.S.C. 777-77k; 64 Stat. 430), as amended

This act, commonly referred to as the “Wallop-Breaux Act”, provides federal funds to states for management and restoration of fish in connection with sport or recreation in the marine and/or fresh waters of the United States.

8.4.1.14 Anadromous Fish Conservation Act (16 U.S.C. 757a-757f; 79 Stat.) as amended

Public Law 89-304 authorizes the Secretaries of the Interior and Commerce to enter into cost sharing agreements with the states and other non-federal interests for conservation, development, and enhancement of the nation's anadromous fish (such as Atlantic salmon, Pacific salmon, shad, and striped bass). Investigations, engineering and biological surveys, research, as well as the construction, maintenance and operations of hatcheries are authorized.

8.4.1.15 National Environmental Policy Act of 1969 (42 U.S.C. 4321-4347; 83 Stat. 852)

Public Law 91-90 requires federal agencies to consult with each other and to employ systematic and interdisciplinary techniques in planning and decision making. It also requires federal agencies to include in every major Federal action significantly affecting the quality of the human environment a detailed statement on (1) the environmental impact of the proposed action; (2) any adverse environmental effects which cannot be avoided should the proposal be implemented; (3) alternatives to the proposed action; (4) the relationship between local short-term uses and enhancement of long-term productivity; and (5) any irreversible and irretrievable commitments of resources involved in the proposed action.

8.4.1.16 Regulations and Permitting for Aquaculture

The U.S. aquaculture industry is subject to the state and federal laws and regulations discussed below. In addition, there are also fish health guidelines available to the industry. The New England Salmonid Health Guidelines published in 1995 and updated in September of 2001 and were developed by a committee to address fish health of salmonids in New England. The guidelines identify requirements for the prevention and control of serious fish pathogens. The guidelines were designed to unify and coordinate the fish pathogen control efforts of member state and federal agencies. They include a system for inspecting fish culture facilities and references to the technical procedures to be used (New England Salmonid Health Committee 1997. New England Salmonid Health Guidelines. On file: Connecticut Department of Environmental Protection, Fish Health Laboratory, Burlington, Connecticut).

Disease risks associated with increased densities of farmed raised Atlantic salmon located in close proximity to salmon rivers has been identified as a threat to native populations of Atlantic salmon in Maine. A major outbreak of Infectious Salmon Anemia Virus (ISAV) in salmon found on salmon farms located in Cobscook Bay in 2001, led the MDMR to promulgate emergency regulations governing fish disease. In 2002, the USDA-APHIS veterinary services program took the lead role for monitoring and surveillance of these regulations through a comprehensive plan that established standards and procedures for the prevention and containment of ISA from farmed raised salmon. Furthermore, to control sea-lice outbreaks on salmon farms integrated pest management guidelines have been established to include monitoring and mandatory treatments. Monitoring of these programs is achieved through routine regularly scheduled bio-security audits as well as mandatory reporting. Effective compliance and implementation of these plans has been

required for participation in an indemnity program for depopulation of ISAV infected farms. While disease risks are minimized through strict bio-security and good fish husbandry practices, disease outbreaks are eminent, as evident in a recent outbreak of ISAV on a Cobscook Bay farm in 2004.

State Regulation of Aquaculture

The MDMR and MDEP are the two state agencies in Maine responsible for processing applications net pen aquaculture permits. As discussed above in section 8.4.1.1.1, the Maine DEP has been delegated authority to issue permits under the NPDES permit program for point source discharges from marine aquaculture facilities and freshwater hatcheries. The Maine DEP General Permit includes special conditions for the protection of Atlantic salmon that are similar to the special conditions in the ACOE section 10 permit. The only substantive difference between the two permits is the implementation dates for the different conditions due to the fact that DEP finalized the General Permit on June 19, 2003, and the ACOE permit was finalized in 2005.

The MDMR is responsible for authorizing aquaculture leases for Atlantic salmon and issuing fish transfer permits. MDMR evaluates a number of different factors including the depth of the water and water velocity at the proposed site, in order to determine whether a particular site can support an Atlantic salmon aquaculture operation without significant adverse impacts to the surrounding marine environment. Once MDMR authorizes a lease, the facility must also acquire a fish transfer permits which essentially authorizes the facility to transport and stock fish at the designated site. Fish transfer permits have standard conditions to address fish health issues including requiring aquaculture operations to implement the USDA-APHIS ISA Program Standards and Response Plan. This program and response plan establishes recommended procedures for the prevention and containment of ISA from farm raised Atlantic salmon. In addition, MDMR also requires aquaculture operations to adhere to the guidelines outlined in the 2002 Finfish Bay Management Agreement and requires aquaculture operations to obtain a new fish transfer permit when transporting fish between lease sites.

MDMR aquaculture lease requirements: PL 1991, c. 381, subsection 2; and Federal regulations and laws include:

1) 50 CFR 16.16, Injurious Wildlife: importation of fish or fish eggs;

2) Rivers and Harbors Appropriation Act of 1899, Section 10; construction of structures in navigable waters;

3) Federal Water Pollution Control Act Amendments of 1972 (33 U.S.C. 1341-1345; 86 Stat.877), as amended, established the National Pollutant Discharge Elimination System Permits; and

4) Fish and Wildlife Coordination Act (16 U.S.C. 661-667e; 48 Stat. 401), as amended; authority for U.S. Fish and Wildlife Service to comment on the effects on fish and wildlife of activities proposed to be permitted by the U.S. Army Corps of Engineers.

These guidelines, regulations and laws address and/or govern the importation of finfish and their eggs, define the location and size of aquaculture facilities, and establish monitoring requirements for disease and environmental impacts.

The Legislature for the state of Maine has amended Public Law 1991, c. 381, subsection 2, specific to aquaculture to prohibit the importation or introduction into any waters of the state, of any Atlantic salmon, live or as eggs, that originate in any Icelandic or European territorial water, or any other species of salmon, exclusive of rainbow trout, originating west of the North American Continental Divide. This law initially provided for the introduction of salmon originating from outside of North America, excluding stocks from west of the Continental Divide, until January 1, 1995.

Federal Regulation of Aquaculture

A joint federal and state of Maine permit processing procedure has been established to facilitate the processing of applications for net-pen aquaculture permits. At the federal level, permits for placement of cages in marine waters are issued by the U.S. Army Corps of Engineers (ACOE) under Section 10 of the Rivers and Harbors Act of 1899. The ACOE issued Standard Siting Requirements and Permit Conditions in 1997; however, in 2005 those permit conditions have been revised to provide additional protections for Atlantic salmon. These special conditions were proposed by the ACOE during consultation with the Services on the proposed modification of existing ACOE permits authorizing the installation and maintenance of aquaculture pens in Maine. The new special conditions are included in all new section 10 permits issued by the ACOE and all existing section 10 permits will be modified. The special conditions include a prohibition on transgenics and the use of reproductively-viable Atlantic salmon originating from non-North American stock. Non-North American stock is defined in these special conditions as any Atlantic salmon that possess genetic material derived partially (hybrids) or entirely (purebreds) from any Atlantic salmon stocks of non-North American heritage, regardless of the number of generations that have passed since the initial introduction of non-North American genetic material. Broodfish will be genetically evaluated and classified as either non-North American or North American utilizing specific microsatellite analysis protocol. Only the progeny of North American origin broodfish will be allowed in net pens.

The special conditions also require aquaculture facilities to employ fully functional marine containment management systems designed, constructed, and operated to prevent the accidental or consequential escape of fish to open water. If a reportable escape event (50 fish 2.0 kg in size or greater) does occur, then the permittee is required to report the event to specified contacts. The special conditions require permittees to mark all Atlantic salmon introduced into net pens to allow the Services or ACOE to identify the origin of a fish in the event of an escape. Lastly, the special conditions state that personnel from the Services and the ACOE are allowed to inspect any of the work authorized by this permit.

Regulation of Aquaculture in Canada

The majority of aquaculture operations in Atlantic Canada are concentrated in New Brunswick. Aquaculture operations in New Brunswick pose a substantial threat to the GOM DPS. Escapees from Canadian net pen sites have the potential to stray into the GOM DPS and pose a threat to wild stocks in the U.S. (see section 8.5). Therefore, regulations used to manage the aquaculture industry in New Brunswick are important to consider.

The Canadian Department of Fisheries and Oceans (DFO) is responsible for regulating commercial aquaculture throughout Canada. DFO has developed the regulatory framework for permitting aquaculture operations. The Provinces are responsible for issuance of aquaculture permits and licenses and regulating farm activities including escapement, siting requirements, waste management, and aspects of aquatic animal health that concern provinces. Specific requirements regulating farm activities differ from Province to Province.

New Brunswick is currently in the process of developing Fish Health Zones that will be applied industry wide. Within these Zones there are currently standards for stocking densities and single year class stocking is being phased in. Eventually, fallowing standards will also be applied to all Zones, however those have not yet been developed. With respect to containment, New Brunswick developed a draft Code of Containment, however, it has not been finalized and is not fully implemented industry wide. New Brunswick has not developed standard protocols to address escape prevention, response planning, or marking. Lastly, escape reporting is not yet mandatory in New Brunswick.

International Guidelines for Aquaculture

In June of 2003 at the 20th annual meeting of NASCO, the Williamsburg Resolution was adopted and then amended at the 21st annual meeting of NASCO in 2004. The Williamsburg Resolution was drafted in Williamsburg, Virginia at the Meeting of the Standing Committee on the Precautionary Approach. The Williamsburg Resolution seeks to minimize impacts from aquaculture introductions and transfers, and transgenics on wild salmon stocks. The Williamsburg Resolution outlines specific measures that each Party should take in order to minimize impacts from aquaculture introductions and transfers including:

(1) Minimize escapes of farmed salmon to a level that is a close as practicable to zero through the development and implementation of action plans as envisaged under the Guidelines on Containment of Farmed Salmon (CNL(01)53);

(2) Minimize impacts of ranched salmon by utilizing local stocks and developing and applying appropriate release and harvest strategies;

(3) Minimize the adverse genetic and other biological interactions from salmon enhancement activities, including introductions and transfers;

(4) Minimize the risk of transmission to wild salmon stocks of disease and parasites from all aquaculture activities and from introductions and transfers.

The Williamsburg Resolution states that Parties should conduct thorough evaluations of potential adverse impact to Atlantic salmon prior to introducing non-indigenous fish into a river system that contains Atlantic salmon. The Parties should only proceed with an introduction if the assessment indicates that there is no unacceptable risk of adverse ecological interactions. With respect to transgenic salmon (Article 7), the Williamsburg Resolution states that Parties should apply the Guidelines for Action on Transgenic Salmon (CNL(97)48) to protect against potential impacts from transgenic salmonids of wild salmon stocks and there should be a strong presumption against any such use. The aforementioned Articles of the Williamsburg Resolution have dealt with preventative measures that Parties should take to minimize adverse impacts from aquaculture, however, the Resolution also contains a provision that advises Parties to initiate corrective measures to address identified adverse impacts.

It is important to note that the Williamsburg Resolution is not a regulatory document that requires Parties to implement any of the articles and any action on the part of the Parties to implement the Williamsburg Resolution is voluntary. However, Parties do have to report annually on their progress on implementing the Williamsburg Resolution; therefore, there is a significant amount of pressure to implement these measures.

The North American Commission (NAC) of NASCO (comprised of the U.S. and Canada) has recognized the potential for adverse fish health, genetic, and ecological effects on native Atlantic salmon stocks. The NAC formally adopted protocols in 1992 (amended 1994) for the introduction and transfer of salmonids that include a zoning concept for the introduction and transfer of salmonids in the Commission area and specific actions regarding fish health and genetic issues, including a prohibition on the use of reproductively viable European or Icelandic stocks. The protocols are not legally enforceable regulations. However, each NAC country, as a signatory to the treaty, has a commitment to take whatever measures are necessary to implement the protocols in their respective country. Canada and the United States agreed upon an updated version of the protocols at the NASCO Annual Meeting in 2005.

Three Zones are identified in the current NAC protocols, and two are applicable to the coastal waters of Maine. Maine, east of Rockland, lies within Zone II and the area west of Rockland lies within Zone III. The proposed revision to the protocols would place rivers within the State of Maine from the Kennebec River drainage eastward in Zone II and west of the Kennebec River drainage in Zone III. Key aspects of protocols that apply to all Zones and that are recommended by NAC for protection of native Atlantic salmon stocks, include:

> (1) Atlantic salmon of European origin, including Icelandic origin, are not to be released or used in aquaculture in the NAC area;
>
> (2) Salmon, eggs, gametes, or fish products are not to be imported from IHN enzootic areas without thoroughly demonstrating the absence of IHN;

(3) Prior to transfer of eggs or fish, at least three health inspections of the donor facility must be completed within a two-year period preceding the transfer to ensure the absence of restricted fish pathogens; and

(4) Prior to movement of non-native fishes to rivers or rearing sites inhabited by Atlantic salmon, the potential for adverse impacts on the productivity of wild salmon populations must be reviewed and evaluated.

5) Hatchery rearing programs to support the introduction, re-establishment, rehabilitation and enhancement of Atlantic salmon should comply with identified selection, spawning and mating procedures.

Within Zone II, reproductively viable non-indigenous species (except Arctic char and Brook trout) and reproductively viable Atlantic salmon stocks, non-indigenous to the NAC area, are not to be introduced into watersheds or into the marine environment.

Atlantic salmon restoration, enhancement, and aquaculture activities are permitted in the freshwater and marine environments. Domesticated broodstock should be developed using local stocks or nearby stocks; non-indigenous stocks may be introduced into the wild or used in cage rearing operations if fish are reproductively sterile and the risk of adverse ecological interactions is minimal. Preferred locations for cage culture are at least 20 km from watersheds managed for Atlantic salmon production.

Within Zone III, indigenous and non-indigenous salmonine and non-salmonine (except reproductively viable Atlantic salmon stocks non-indigenous to the NAC Area) fishes may be considered for introduction or transfer if fish health and genetic protocols are followed, and negative impacts on Atlantic salmon can be shown to be minimal. Use of local stocks in cage culture or salmon farms is preferred, but non-indigenous stocks may be cultured. Cage culture or salmon farming can be widely practiced yet preferred locations are at least 20 km from watersheds managed for Atlantic salmon production.

Summary of Aquaculture Regulations

Threats to wild salmon may occur if farmed salmon transmit diseases or parasites to remnant populations of wild Atlantic salmon within any of the listed rivers or the nearshore marine environment when wild salmon migrate through marine waters adjacent to sea cages; if farmed salmon escapees interbreed with wild salmon and cause reduced fitness for survival; if farmed salmon superimpose redds on wild salmon redds, thus disrupting the egg incubation process; or if farmed salmon escape as juveniles into the salmon rivers and compete for food and space with wild stocks. Furthermore, potential threats from any poor hatchery practices in freshwater fish culture could affect wild salmon. The Services do have the opportunity to review and comment on the operation of freshwater fish hatcheries within the range of the GOM DPS (as listed in 2000) through the MPDES process.

8.4.2 Interstate and Interagency Committees

In accordance with various interagency cooperative agreements, the following governmental agencies participate directly in New England salmon programs: USFWS, NMFS, U.S. Forest Service, MDMR, MDIFW, MASC, New Hampshire Fish and Game Department, Massachusetts Division of Marine Fisheries, Massachusetts Division of Fish and Wildlife, Rhode Island Division of Fish and Wildlife, Vermont Department of Fish and Wildlife, and the Connecticut Department of Environmental Protection.

The committees listed below have the potential to significantly influence issues related to Maine-origin Atlantic salmon.

8.4.2.1 Maine Technical Advisory Committee - established 1980

This committee succeeded an earlier group (Research Committee) and is an interagency committee with members from the three state fishery agencies in Maine, the University of Maine, the Penobscot Indian Nation, and the Services. The Technical Advisory Committee reviews activities associated with Atlantic salmon management in Maine and recommends appropriate actions to the MASC, USFWS, and NMFS.

8.4.2.2 New England Atlantic Salmon Committee - established 1984

This committee is composed of all state and federal fishery agency directors in New England. It addresses broad policy issues related to salmon restoration and interacts with the U.S. Commissioners to the North Atlantic Salmon Conservation Organization.

8.4.2.3 New England Salmonid Health Committee - established 1985

This group of fish health specialists was originally established by the New England Atlantic Salmon Committee to address policy issues and provide guidelines related to Atlantic salmon disease management and other health needs related to salmon culture and restoration for both commercial aquaculture and conservation hatcheries. Originally established only to address Atlantic salmon, their charge was expanded to all regional salmonid health issues in 1987.

8.4.2.4 U.S. Atlantic Salmon Assessment Committee (USASAC)

This committee is composed of state and federal fishery staff who provide advice and input to the three U.S. Commissioners to NASCO. The USASAC focuses on preparing annual stock assessments and the proposal and evaluation of research needs.

8.4.3 State Regulations

The state of Maine has numerous laws that regulate the diversity of activities that could potentially affect anadromous Atlantic salmon. Development is regulated by the Model Shoreland Zoning Act, the Land Use Regulation Commission and Natural Resource Protection Act. Three agencies have authority over forest practice regulations: the Land Use Regulation Commission, the Department of Environmental Protection, and the Maine Forest Service. Maine also has regulations regarding non-point source pollution control and pesticide application control.

State laws that offer Atlantic salmon and their habitat protection are summarized in the Conservation Plan (MASTF 1997). Although the Conservation Plan specifically addresses seven rivers in Maine, the laws summarized in the Plan represent all of the state laws in Maine that protect Atlantic salmon and their habitat. In March 1998, the Maine legislature passed a new law, which has the potential to reduce non-point source pollution from Maine agriculture. That law, An Act Regarding Nutrient Management (7 MRSA Ch 747), requires all Maine farms with more than 50 animal units (1 unit = 1000 lbs of body weight) to develop a whole farm nutrient management plan by January 1, 2001. The law also prohibits winter spreading of manure. The Commissioner of Agriculture is granted authority for enforcing these regulations (LWRC 1999). The following summary highlights state regulations that are most relevant to the management and conservation of Atlantic salmon.

Special Protection for Outstanding Rivers (MSRA Title 12 Chapter 200 §401-407)
The Maine Legislature has declared special protection for certain rivers due to their unique natural features and importance to the ecosystem in Maine. By declaring special protections for these rivers, no new water diversion (i.e. constituting a hydropower project pursuant to Title 38, section 632,) that would bypass all or part of the natural course of these river and stream segments will be permitted to be constructed without the specific authorization of the Legislature. Furthermore, additional development or redevelopment of dams existing on these segments, as of September 23, 1983, shall be designed and executed in a manner that either enhances or does not diminish the significant resource values of these river segments identified by the 1982 Maine Rivers Study. Any project that fails to meet the standards outlined will be considered to violate Maine's Water Quality Standards and be in violation of the United States Clean Water Act.

8.4.3.1 Fishways (MRSA Title 12; Part 9; Sub-part 1; Chapter 605; Sub-Chapter 4; §6121-6125)

The Commissioner of the Department of Marine Resources and Inland Fisheries and Wildlife have the authority to require a fishway to be erected, maintained, repaired or altered by the owners, lessors or any other individual responsible for the operation of an artificial obstruction within coastal and inland waters in order to conserve and restore anadromous and migratory fish populations. In order to ensure that areas upstream of artificial obstructions are accessible to anadromous fish populations, the Commissioner has the authority on an annual basis to examine all dams and other artificial obstructions to fish passage to determine if fishways are present, sufficient and suitable for passage. If the Commissioner does determine that a fishway must be constructed or repaired, a finding must be made that either: a) one or more species of anadromous or migratory fish can be restored in substantial numbers to the watershed and the habitat above the obstruction may possibly be able to support commercial or recreational fisheries for the species; or b) the construction and/ or repair to the fishway is necessary to protect or enhance rare, threatened, or endangered fish species.

With respect to the construction of a new dam or artificial obstruction, the individual proposing the construction must submit construction plans to the Commissioner for

review. The Commissioner then shall review the plans in order to determine whether fishway construction or alteration of proposed fishway construction plans may be required.

8.4.3.2 Endangered or Threatened Marine Species (MRSA Title 12; Part 9-subpart 2; Chapter 631; §6971-6977)

The Commissioner for the Department of Marine Resources may recommend a marine species found in the State for designation as a state endangered or state threatened marine species if that species is listed as an endangered or threatened species by the United States Secretary of the Interior, pursuant to the United States Endangered Species Act of 1973. The Commissioner may then implement programs to conserve and protect these species in order to try and achieve the goals of the Federal Endangered Species Act. Atlantic salmon are not currently listed on the State of Maine Endangered and Threatened Species List.

8.4.3.3 Shoreland Zoning Act (MRSA Title 38; Chapter 3; Sub-chapter 1; §435-449)

In order to conserve and protct human and environmental health shoreland areas are subject to zoning and land use controls by the state of Maine's Shoreland Zoning Act. Shoreland areas include those areas within 250 feet of the normal high-water line of any great pond, river or saltwater body, within 250 feet of the upland edge of a coastal wetland, within 250 feet of the upland edge of a freshwater wetland, or within 75 feet of the high-water line of a stream. The purposes of these controls are to further the maintenance of safe and healthful conditions; to prevent and control water pollution; to protect fish spawning grounds, aquatic life, bird and other wildlife habitat; to protect buildings and lands from flooding and accelerated erosion; to protect archaeological and historic resources; to protect commercial fishing and maritime industries; to protect freshwater and coastal wetlands; to control building sites, placement of structures and land uses; to conserve shore cover, and visual as well as actual points of access to inland and coastal waters; to conserve natural beauty and open space; and to anticipate and respond to the impacts of development in shoreland areas.

8.4.3.4 Classification of Maine Waters (MRSA Title 38; Chapter 3; § 464-470)

The Maine Legislature established a water quality classification system for all surface waters within the state in order to manage its surface waters to protect the quality of those waters and, where water quality standards are not being achieved, to enhance water quality. The classification system is based on water quality standards that designate the uses and related characteristics of those uses for each class of water and which also establish water quality criteria necessary to protect those uses and related characteristics. The Legislature created the classification system in such a way so that each of the state's surface water bodies is assigned the water quality classification that represents the minimum level of quality that the Legislature intended for the body of water. Based upon the designated classification for the water body, the state will be required to manage accordingly to continue to enhance water quality in surface water throughout Maine.

8.4.3.5 Draft Sustainable Water Use Rules (*Sec. 12. 38 MRSA §470-H)*

The Draft Sustainable Water Use Rules establish water use standards for maintaining in-stream flows and GPA lake or pond water level that are protective of aquatic life and other uses. These water use rules should also establish criteria for designating watersheds most at risk for cumulative water use. The standards that are adopted must be based on the natural varation of flows and water levels and should allow some amount of variation if water use is still protective of water quality and aquatic life within that classification. Maine DEP is currently summarizing comments collected during the public comment period after which they will commence with formal rulemaking.

8.4.3.6 An Act to Require Major Water Users to Provide Public Information About Their Annual Water Withdrawals from Public Water Resources (Sec 1. 38 MRSA c.3, sub-c I, art 4-B)

This Act was created in 2002 for the purposes of requiring major water users to report information regarding their water use to the commissioners identified in the Act. Major water use is considered to be anything higher than the threshold levels stated in the Act. The commissioner is then directed to report a summary of the water use to the Legislature on an annual basis. Certain users are exempt from reporting and reporting requirements for major users are not enforced. This Act also directed the state to develop the Sustainable Water Use Rules by January of 2005 and encourages State, local, and municpal agencies to develop water use plans to help guide water use in specific watersheds.

8.4.3.7 Natural Resource Protection Act(MRSA Title 38; Chapter 3; Sub-chapter 1; Article 2-B; §435-449)

The Legislature has declared that the state's rivers and streams, great ponds, fragile mountain areas, freshwater wetlands, significant wildlife habitat, coastal wetlands and coastal sand dune systems are resources of state significance. However, it was recognized by the Legislature that many of these resources were being destroyed due to a number of factors despite their importance economic and environmental importance. In an effort to preserve these unique environmental resources, the state of Maine requires a permit when a proposed activity is: (1) located in, on, or over any protected natural resources; or (2) located adjacent to (A) a coastal wetland, great pond, river, stream or brook or significant wildlife habitat contained within a freshwater wetland, or (B) certain freshwater wetlands. Activities that require a permit are as follows: (A) dredging, bulldozing, removing or displacing soil, sand, vegetation or other materials; (B) draining or otherwise dewatering; (C) filling, including adding sand or other material to a sand dune; or (D) any construction, repair or alteration of any permanent structure.

8.4.4 Summary of Inadequate Regulatory Mechanisms

A variety of state and federal environmental statutes and regulations seek to address potential threats to Atlantic salmon and their habitat. These laws are complemented by

international actions under NASCO and many interagency agreements and state-federal cooperative efforts. Implementation and enforcement of these laws and regulations could be strengthened to further protect Atlantic salmon. The appropriate state and federal agencies have established coordination mechanisms and have joined with private industries and landowners in partnerships for the protection of Atlantic salmon. While these partnerships are important to the recovery of the species, the existing regulatory mechanisms discussed below either lack the capacity or have not been implemented adequately to decrease or remove the threats to wild Atlantic salmon. The discussion that follows will focus on those laws that are not sufficient to deal with threats or, if they are adequate, are not being applied or enforced. Major threats continue to be impediments to fish passage; poor marine survival; water withdrawals; habitat degradation; poor water quality; recreational fishing mortality; disease and aquaculture impacts; and predation and competition.

8.4.4.1 Fish Passage

The effects of ineffective and non-existent fish passage are described in detail in section 8.1. Simply put, Atlantic salmon require a diverse array of well connected habitat types in order to complete their life history. Present conditions within the range of the GOM DPS only allow salmon to access a fraction of river miles that were historically accessible. Even where salmon can presently access suitable habitat, they must often pass several dams to reach their natal spawning habitat.

Most hydroelectric dams in the large watersheds of the GOM DPS (Penobscot, Kennebec, and Androscoggin) are licensed by FERC under the Federal Power Act (see section 8.4.1.10). Section 18 of the Federal Power Act authorizes the Services to prescribe upstream and downstream fishways. At present, many hydroelectric dams within the range of the GOM DPS are impassible due to the lack of fishways. Other hydroelectric dams allow passage; however, upstream passage effectiveness for anadromous fish species never reaches 100% and substantial mortality and migration delays occur during downstream passage events. The cumulative losses of smolts, in particular, incrementally diminish the productive capacity of freshwater rearing habitat above hydroelectric dams (see Section 8.1). For example, if a given reach that can produce 100 smolts is above five hydroelectric dams that each have 90% effective downstream fish passage facilities, the total amount of smolts produced by that reach in a given year is effectively reduced to about 59 smolts. The BRT is not aware of any section 18 prescriptions in Maine that account for such cumulative losses in production capacity.

Several existing FERC licenses for hydroelectric projects in the Penobscot, Kennebec, and Androscoggin Rivers do not require any upstream or downstream passage for salmon. In these cases, reservations of section 18 authority are often in place that could allow fishways to be prescribed by the Services. However, a substantial amount of mortality and passage inefficiency would still occur given that fish passage facilities are never 100% efficient. In addition, any new fishway prescriptions could be extremely

contentious and any resultant changes could take several years to allow the FERC rehearing process to run its course.

Furthermore, fish passage alone is not the only threat to salmon caused by hydroelectric dams. The effects of habitat degradation (see Section 8.1) and the altered environmental features that favor non-native species (see Section 8.3) pose an equal or even greater impediment to Atlantic salmon recovery via reduction in production capacity of freshwater rearing areas above dams. In Maine, Sections 10(a) and 10(j) of the Federal Power Act could be used by the Services to minimize these effects, but these regulatory mechanisms are largely discretionary and oftentimes not required by the FERC (see Section 8.4.1.10; Black et al. 1998). Section 4(e) of the Federal Power Act is oftentimes used by the Services to recommend fisheries enhancements; however, federal lands applicable to Section 4(e) are rare in Maine.

In order for a hydropower project to be re-licensed by the FERC, the state of Maine must first certify that continued operation of the project will comply with Maine's water quality standards pursuant to Section 401 of the Clean Water Act. The Maine DEP is the certifying agency for all hydropower project licensing and re-licensings in the state of Maine except for projects in unorganized territories subject to permitting by the Land Use Regulation Commission. Through the water quality certification process, the Maine DEP can require fish passage and habitat enhancements at FERC licensed hydroelectric projects.

However, the vast majority of dams within the range of the GOM DPS do not require either a FERC license or Maine DEP water quality certificate. These non-jurisdictional dams are typically small, non-generating dams that were historically used for a variety of purposes including flood control, storage, process water, etc. Practically all of these dams within the range of the GOM DPS do not have fish passage facilities and are impacting historical Atlantic salmon habitat. Many of these non-jurisdictional dams are no longer used for their intended purposes; although, many smaller dams maintain water levels in lakes and ponds. Although the Maine DEP can be petitioned by the public to set minimum flows and water levels at these dams, the DEP has no direct statutory authority under Maine law to require fisheries related enhancements without public request or petition. Removal of non-hydropower generating dams in Maine may require a permit under the Natural Resources Protection Act or the Maine Waterway Development and Conservation Act. Owners of non-hydroelectric dams can petition the Maine DEP to be released from ownership; however, the Maine DEP does not have the authority to require dam removal without the consent of the owner.

The Penobscot River Restoration Project (PRRP) and the agreement between members of the Kennebec Hydro Developers Group (KHDG) offer some promise toward reconnecting Atlantic salmon with portions of their historic range. However, many miles of otherwise suitable habitat remain inaccessible throughout the Penobscot (i.e., West Branch), Kennebec, Androscoggin, and many smaller rivers. The inability to access substantial amounts of their former range diminishes the GOM DPS' ability to cope with

stochastic events (see Section 3.3.5). Further, direct mortality attributable to dams decreases the production capacity of freshwater rearing habitats above passable dams.

Under the current FERC process, dams are not licensed collectively at the watershed scale. Rather, they are conducted on a case by case basis. This does not allow for a comprehensive, cumulative analysis of each successive dam. Further, the BRT has suggested throughout this Status Review that restoration the GOM DPS may require the concurrent restoration of many other diadromous fish that salmon co-evolved with (see Section 8.5.4 for a detailed review). Clearly, habitat losses associated with hydroelectric and non-hydroelectric dams are not being considered from an ecosystem perspective.

8.4.4.2 Water withdrawals

Maine has made substantial progress in regulating water withdrawal for agricultural use. The Land Use Regulatory Commission must approve requests for withdrawals for irrigation in unorganized towns, and can curtail withdrawals if water levels go below what is considered necessary for the well being of the species. Maine DEP has the authority to regulate water withdrawals from organized municipalities in the state but does not now utilize that authority resulting in water withdrawals in organized municipalities being currently unregulated.

The state of Maine has recently enacted legislation (LD 1488) that requires the Maine DEP to work with state, regional and local agencies to develop water use policies that protect the environment from excessive drawdown of water sources including rivers, lakes, streams, and ground water, during low flow periods, and requires major water users to report any use that is above threshold levels. The commissioner is then required to submit a summary report on major water uses to the legislature on annual basis. The commissioners have been submitting an annual report to the legislature, although reporting requirements are not enforced and thus it is unclear if all major water user are indeed reporting their withdrawals. It is also unclear how many local and municipal agencies have developed additional water use policies. Furthermore, these policies consider general effects on the environment; no special consideration is required for the protection of Atlantic salmon or its habitat. The Sustainable Water Use Rules will offer important protection for aquatic species and help maintain higher water quality; however, they have not been finalized. Until these water use policies are fully developed and effectively implemented to specifically protect Atlantic salmon, water withdrawals remain a threat to the GOM DPS.

8.4.4.3 Water Quality

Maine DEP issues NPDES permits for point source discharges from freshwater hatcheries, municipal facilities, and other industrial facilities. Currently, the Services review and comment on NPDES permits issued to facilities that discharge within the range of the GOM DPS (as listed in 2000). Maine DEP could potentially be permitting discharges that may not consider adverse effects on the population in the Penobscot. There is currently no regulatory mechanism that would require DEP to seek the Services review and comments on NPDES permits that are being issued in river systems where

populations of Atlantic salmon are not currently listed under the ESA. OBDs will continue to contribute to poor water quality throughout the state until the regulatory phase out is complete.

The NMFS Habitat Conservation Division does have the opportunity to comment on draft NPDES permits with respect to potential affects on EFH. However, Maine DEP is not required to submit NPDES permits to NMFS Habitat Conservation Division prior to issuing the final permit. NMFS Habitat Conservation Division does not consistently review and comment on NPDES permits and potential effects on Atlantic salmon EFH.

8.4.4.4 Recreational Fishing Mortality

In December of 1999, all angling for Atlantic salmon was prohibited by the MASC in all Maine waters including coastal waters. The MASC has also promulgated regulations prohibiting all types of angling in certain areas where Atlantic salmon congregate and could potentially be captured. On the Penobscot River the MASC has closed all angling at the Veazie Pool due to observed striped bass angling that resulted in the mortality and serious injury of three Atlantic salmon in 2001. However, this year (2005), the MASC proposed the authorization of a very limited catch and release recreational fishery in the area below Veazie. Given that there is an active restoration program on the Penobscot River, the proposal was brought before the Maine Atlantic Salmon Technical Advisory Committee (TAC) to seek advice on the potential level of risk that the proposed fishery may pose to the Penobscot population and the GOM DPS (as listed in 2000). The state had not made a decision at the time of writing this Status Review.

Continuation of fishing for other species leaves the threat of incidental capture of adults and parr throughout the rest of the Penobscot River and other salmon rivers in Maine, notwithstanding that this would be a violation of section nine of the ESA if it occurred within the range of the GOM DPS (as listed in 2000). In addition to recreational fisheries for native species, currently non-native species are also stocked throughout the state. Stocking of non-native fish may diminish freshwater production of juvenile Atlantic salmon through competition and predation (see Section 8.3 for a detailed review) as well as increase the risk of incidental capture of Atlantic salmon. While the MASC and the Services have taken steps to minimize poaching and incidental capture of Atlantic salmon, stocking of non-native species, poaching, and incidental capture continue to occur.

8.4.4.5 Disease

A number of state and federal laws exist to reduce the threats to both wild and cultured fish from disease. Maine has very stringent fish health requirements, and the USFWS monitors hatchery fish at Craig Brook and Green Lake. Cultured fish are vaccinated against various diseases and screened continuously. However, in spite of regulations, the European ISA virus has become established in North American aquaculture fish in proximity to wild Atlantic salmon in the Penobscot River. In the past, disease episodes have compromised the Services' river specific stocking program in that Pleasant River broodstock had to be destroyed and brood stock for three other wild river populations has

been compromised. As a result, disease outbreaks do pose an ongoing threat to the GOM DPS and the associated hatchery populations.

8.4.4.6 Aquaculture

Aquaculture operations pose a significant risk to wild stocks of Atlantic salmon. The Services have worked in conjunction with the state of Maine and ACOE over the past four years with the industry to minimize threats posed by aquaculture operations, through improved containment practices, marking, limiting stocks in culture to North American, and instituting bay management. However, there is still the risk of an escape event to occur at a net pen site and for aquaculture escapees to adversely affect wild stocks of Atlantic salmon. The marking regime outlined in both the NPDES and ACOE permit conditions require phase in time that means aquaculture fish are not required to have a site specific mark until 2007. Marking aquaculture fish will aid in the identification of aquaculture origin individuals at locations where weirs are in place, or when escape events have occurred and targeted angling is attempted to capture escapees. Marking also aids in later life stages, such as if reproduction by the aquaculture origin individual occurs, then their offspring may be identified if genetic marks are used. However, during the interim it may be difficult to determine from which individual facility an escapee occurs. Without this information it is difficult to evaluate the effectiveness of containment measures and to take corrective action to reduce the risk of future escapes. Lastly, the prohibition on the placement of reproductively viable non-North American origin Atlantic salmon was not effective until recently. As a result, reproductively viable non-North American origin Atlantic salmon have the potential to be present in net pens until March of 2006 when the Services have required their removal. Thus, non-North American aquaculture fish may interbreed with native fish during the fall of 2005 or 2006..

It is difficult to evaluate the effectiveness of the special permit conditions that protect wild Atlantic salmon within the range of the GOM DPS. DEP only recently issued the final permit and are currently in the process of revising existing permit conditions for existing and new aquaculture facilities. The ACOE has only recently issued final permit language for the Section 10 permits; therefore, the ACOE is currently in the process of revising existing permits and issuing new ones for aquaculture operations within the range of the GOM DPS (as listed in 2000). Without full implementation and enforcement of these permit conditions, aquaculture would continue to pose a significant risk to the GOM DPS.

8.5 Other Natural or Manmade Factors Affecting the Continued Existence of the GOM DPS

8.5.1 Artificial Propagation

Captive propagation and maintenance of broodstocks can be used to sustain or supplement threatened or endangered fish populations (Flagg and Nash 1999). Though potentially effective at maintaining or increasing the population size, there is potential for altering unique genetic characteristics of the natural population (Berejikian and Ford 2004). Mating strategies used in hatchery propagation can reduce genetic variability

inherent in populations through artificial reductions in the number of spawning adults through reproductive variation (Withler 1988). Artificial selection may alter population-specific life history or genetic traits that may both alter the genetic characteristics of the captive population in relation to the wild source population, or result in decreased ability of the population to survive in the natural environment (Berejikian and Ford 2004). Therefore, implementing hatchery practices that minimize artificial selection are important to maintain population-specific genetic characteristics and within-population genetic diversity.

As population sizes decrease, and the potential for mating related individuals increase, the threat of inbreeding in a population also increases. Inbreeding has been documented to decrease overall fitness of a population (Spielman et al. 2004, Lynch and O'Hely 2001), reducing the long-term population viability and therefore inhibiting the success of restoration and recovery efforts. Similarly of concern is the threat of outbreeding depression, and decreased fitness resulting from the mating of individuals from significantly genetically different populations.

Starting in 1992, a river-specific broodstock and stocking program was implemented for rivers in Maine (Bartron et al. 2006). This strategy complies with NASCO guidelines for stock rebuilding (USASAC 2005). The stocking program was initiated for the following two reasons: runs were declining in the seven rivers in the DPS and numerous studies indicated that restocking efforts are more successful when the donor population comes from the river to be stocked. This river-specific stocking policy is consistent with the goal of the Maine Atlantic salmon program to maximize production of wild smolts by restocking river specific stocks and emphasizing fry releases (Moring et al. 1995, Bartron et al. 2006). The numbers of returning adult Atlantic salmon to the rivers were very low, and artificial propagation had the potential to increase the number of juvenile fish in the river through fry and other early life stage stocking. Current practices of fry stocking and recovery of parr for hatchery rearing ensures that river-specific spawning stock is available for future production.

Atlantic salmon from the Narraguagus, Pleasant, Sheepscot, Machias, East Machias, and Dennys populations are maintained at Craig Brook National Fish Hatchery (CBNFH; Bartron et al. 2006), in East Orland, Maine. Additionally, adult Atlantic salmon are trapped at the Veazie Dam on the Penobscot River, transferred to CBNHF and held until spawning in the fall of each year. Adult Atlantic salmon (with the exception of the Penobscot River) are maintained in one of six river-specific broodstock rooms, one room is designated per river. Within each broodstock room, adults are maintained separately by capture year. Capture year is defined as the year parr were collected from a river. Each capture year may represent one to two year classes. In addition, fully captive lines, or "pedigree lines" can and are implemented when the recovery of parr from the river environment is expected to be low to ensure future spawning stock is available (Bartron et al. 2006). Pedigree lines are established at the time of stocking, where a proportional representation of each family from a particular river-specific broodstock is retained in the hatchery while the rest of the fry are stocked into the river. If parr are recovered from the fry stocking for the pedigree lines, individuals are screened to determine origin and

familial representation, and are integrated into the pedigree line to maintain some component of natural selection.

The goals of the captive propagation program include maintenance of the unique genetic characteristics of each river-specific broodstock, and maintenance of genetic diversity within each broodstock (Bartron et al. 2006). The Recovery Plan (NMFS and USFWS 2004), and National Research Council review of Atlantic salmon in Maine (2004) both suggest that the primary goal of hatchery management is to maintain genetic variability inherent within each river-specific population and minimizing the potential for inbreeding. Evaluation of estimates of genetic diversity within captive populations, such as average heterozygosity, relatedness coefficients, and allelic diversity and frequency are monitored within the hatchery broodstocks according to the CBNFH Broodstock Management Plan (Bartron et al. 2006).

Spawning practices at CBNFH are described in Burke and Tozier (2002), Buckley (2002a), Buckley (2002b), and Bartron et al. (2006). Spawning has historically occurred among individuals within capture years for each river. During spawning at CBNFH, records are kept to track each male and female spawned, specific spawning pairs, and the lot number assigned to the resulting offspring. Mating strategies typically used are chosen based on their ability to maintain genetic diversity (one male to one female). Genotypic characterization of individuals used for spawning allows for monitoring of estimates of genetic diversity. Genetic characterization typically occurs when individuals are parr, therefore genetic information can be obtained prior to utilization of individuals for spawning.

The captive rearing and spawning practices that are used at CBNFH are focused on achieving the goals of maintaining population-specific genetic diversity and minimizing the risks inherent to a captive propagation program. Broodstock management is evaluated annually and is revised as needed to minimize the potential for inbreeding and maintain genetic diversity Bartron et al. (2006). At this time, domestication and inbreeding depression do not appear to be negatively impacting the hatchery dependent populations of the GOM DPS since the establishment of the current captive broodstock program; however, the historical loss of diversity cannot be dismissed (Lage and Kornfield 2006).

Although the captive broodstocks at CBNFH and the overall hatchery programs at CBNFH and GLNFH are intensively managed to maintain genetic diversity, there are a number of risks associated to the captive propagation programs. Although actions can be implemented to minimize these risks, many risks can not be fully removed from the captive propagation program, including potential risks that are currently unknown or can not be managed against. The hatchery program for the GOM DPS Atlantic salmon in Maine is currently limited to CBNFH, with additional capacity at GLNFH. Incorporating river-specific broodstocks for additional populations is currently limited by space and biosecurity constraints. Location of the six currently maintained river-specific broodstocks at a single facility is also considered a risk due to the possibility of a catastrophic event, which could result in the loss of one or all of the river-specific

broodstocks. As pedigree lines become established, natural selection from fry to parr stage may no longer be incorporated into the life cycle if parr are not recovered in numbers sufficient for broodstock and spawning requirements. Removal of natural selection and artifical selection for the hatchery environment is considered a threat to long term survival (Hey et al. 2005).

8.5.2 Aquaculture

The development and expansion of Atlantic salmon aquaculture has occurred in the North Atlantic since the early 1970s. Production of farmed Atlantic salmon in 2003 was estimated at over 1.1 million tons worldwide, 761,752 tons in the North Atlantic, and 6,435 tons in Maine (ICES 2004). In the mid 1990s, twenty-five to 40% of the fish in the North Atlantic Ocean (north of the Faroes) were of aquaculture origin (Jonsson 1997). In Norway, the number of salmon that escape from sea cages is thought to be greater than the number of salmon in the wild (Gausen and Moen 1991). Between 1992 and 1997, the total stock size of wild and hatchery origin adult Atlantic salmon returning to the Canadian Maritimes was between 115,000 and 229,000. During that same time, the number of salmon in net pens in the Bay of Fundy exceeded 15 million (DFO 1999).

The Maine Atlantic salmon aquaculture industry is concentrated in Cobscook Bay near Eastport, Maine. The industry in Canada, just across the border, is approximately twice the size as the Maine industry. Five freshwater hatcheries in the U.S. have provided smolt to the sea cages and produce up to four million smolt per year. In 2004, only two of these hatcheries were producing smolts.

Three primary broodstock lines are used for farm production. The lines include fish from the Penobscot River, St. John River, and historically an industry strain from Scotland. The Scottish strain was imported into the U.S. in the early 1990s and is composed primarily of Norwegian strains, frequently referred to as Landcatch. In recent years, milt of Norwegian origin has been imported by the industry from Iceland (Baum 1998). However, the recent prohibition on the placement of reproductively viable non-North American origin Atlantic salmon is currently being implemented (see Section 8.4). Thus, non-North American origin Atlantic salmon will no longer be allowed in net pens by March 1 of 2006.

Escaped farm salmon are known to return to Maine. In 1990, at least 17 percent (14 of 83 fish) of the rod catch in the East Machias River were captive reared adults. The proportion of captive reared adults in the adult runs of rivers adjacent to aquaculture operations tends to vary greatly annually (Table 8.5.2a). In addition to the frequency and magnitude of escape events that drive annual variability, returns of captive reared adults to Maine rivers are influenced by the amount of production and proximity of rearing sites in adjacent bays. About 60 percent of commercial salmon production in Maine occurs at sites on Cobscook and Passamaquoddy Bays, into which the Dennys and St. Croix Rivers flow; 35 percent on Machias Bay and the estuary of the Little River, within seven miles of the Machias and East Machias Rivers; and the remainder occurs on the estuaries of the Pleasant and Narraguagus Rivers, or adjacent to Blue Hill Bay. The percentage of captive reared fish in adult returns is highest in the St. Croix and Dennys Rivers and lowest on Penobscot River (less than 0.01% in the years 1994 to 2001), with the

Narraguagus runs having low and sporadic proportions of captive reared salmon. Captive reared salmon returning to Maine rivers include mature males and females. Of 45 captive reared fish examined from the St. Croix, Dennys, and Narraguagus Rivers (1998 to 2000), 10 females and 8 males were mature, 9 females and 16 males were immature, and maturity could not be determined for 8 females and 10 males. Fleming et al. (2000) noted that mature females were the principal route of gene flow between wild and aquaculture salmon populations.

Table 8.5.2a. Weir and fishway trap catches of Atlantic salmon and the percent of that catch that was captive reared adults (suspected aquaculture escapes) from 1994 to 2004.

Year	St. Croix		Dennys		Narraguagus	
	Trap Catch	% Captive	Trap Catch	% Captive	Trap Catch	% Captive
1994	181	54	47	89	52	2
1995	60	22	9	44	56	0
1996	152	13	31	68	64	22
1997	70	39	-	-	37	0
1998	65	37	-	-	22	0
1999	36	64	-	-	35	8
2000	30	60	30	97	23	0
2001	44	51	58	71	22	0
2002	25	20	6	67	8	0
2003	24	37	11	18	21	0
2004	14	28	1	0	11	0

Escapes also occur in neighboring Canadian provinces. In 1994 there was one reported escape in New Brunswick between 20,000 and 40,000 fish, which was equal to the total estimated wild returns to Nova Scotia and New Brunswick that same year (ICES 1994). Since the aquaculture industry began in 1979 in the Maritimes, escapees have been documented in 14 rivers in New Brunswick and Nova Scotia (DFO 1999). The Magaguadavic River is monitored for interactions between wild and farmed fish in Canada. In at least two years, over 90% of the adult salmon entering the Magaguadavic River were of farmed origin. These data indicate that the three aquaculture hatcheries in the watershed were leaking farmed juveniles. Emigrating smolts in 1996 were 51 to 67% farm-origin and those exiting the river in 1998 were 82% farm-origin (DFO 1999). Analysis of eggs taken from the Magaguadavic River in 1993 revealed that at least 20% of redds were constructed by females of farm or cultured origin, and another 35% were of possible cultured origin (Carr et al. 1997).

Atlantic salmon that escape from farms and hatcheries pose a threat to native Atlantic salmon populations (Naylor et al. 2005). Because captive reared fish are selectively bred to promote behavioral and physiological attributes desirable in captivity (Hindar et al. 1991, Utter et al. 1993, Hard et al. 2000). Experimental tests of genetic divergence between farmed and wild salmon indicate that farming generates rapid genetic change as

a result of both intentional and unintentional selection in culture and that those changes alter important fitness-related traits (McGinnity et al. 1997, Gross 1998). Consequently, aquaculture fish are often less fit in the wild than naturally produced salmon (Fleming et al. 2000). Annual invasions of adult aquaculture salmon have the potential to disrupt local adaptations and reduce genetic diversity of wild populations (Fleming et al. 2000). Bursts of immigration also disrupt genetic differentiation among wild Atlantic salmon stocks, especially when wild populations are small (Mork 1991). Natural selection may be able to purge wild populations of maladaptive traits but may be less able to if the intrusions occur year-after-year. Under this scenario, population fitness is likely to decrease as the selection from the artificial culture operation overrides wild selection (Hindar et al. 1991, Fleming and Einum 1997), a process called outbreeding depression. The threat of outbreeding depression is likely to be greater in North America where aquaculture salmon have been based, in part, on European Landcatch strain. Among-family variance in survival (a negative correlate of population persistence) was higher among hybrids of aquaculture strain and Inner Bay of Fundy strains than it was among the pure crosses (Lowler and Hutchings 2004).

Aquaculture escapes of European origin or hybrids can be detected based on the large differences in allele frequencies between populations from different continents (King et al. 2001). The numbers of parr and adults with non-North American lineage collected as broodstock for the Penobscot river and GOM DPS restoration efforts have varied among rivers over time (USASAC 2006). Consistent with these screening results, Lage and Kornfield (2006) found one fish with a European/Newfoundland mtDNA haplotype in Dennys 1995 broodstock. The genetic screening detects possible juvenile escapes from aquaculture hatcheries (on the Pleasant and East Machias) or introgression from spawning aquaculture escapes with non-North American ancestors (Table 8.5.2b). Hybridization between non-north American aquaculture salmon and wild Inner Bay of Fundy stocks has also been reported (O'Reilly et al. 2006).

Table 8.5.2b. The number of individuals, listed by drainage and year, identified for removal from the CBNFH broodstock due to assignment to non-North American populations.

River	Collection Year								
	1994	1995	1996	1998	1999	2000	2001	2002	2003
Parr									
Dennys	0	2	0	13	0	1	1	2	3
East Machias	0	0	0	1	0	0	0	0	0
Machias	0	0	0	1	0	3	0	1	0
Narraguagus	0	0	0	0	0	0	0	3	3
Pleasant	0	0	0	0	4	13	0	0	1
Sheepscot	3	0	1	0	0	0	0	0	2
Adults									
Penobscot	0	0	0	0	0	5	9	0	0

In addition to genetic effects, escaped farmed salmon can disrupt redds of wild salmon, compete with wild salmon for food and habitat, transfer disease or parasites to wild salmon, and degrade benthic habitat (Windsor and Hutchinson 1990, Saunders 1991, Youngson et al. 1993, Webb et al. 1993, Clifford et al. 1997). Farmed salmon in have been documented to spawn successfully, but not always at the same time as wild salmon (Lura and Saegrov 1991, Jonsson et al. 1991, Webb et al 1991, Fleming et al 1996)). Late spawning aquaculture fish could limit wild spawning success through redd superimposition. There has also been recent concern over potential interactions when wild adult salmon migrate past closely spaced cages, creating the potential for behavioral interactions, disease transfer, or interactions with predators (Lura and Saegrov 1991, Crozier 1993, Skaala and Hindar 1997, Carr et al. 1997, DFO 1999). In Canada, the survival of wild postsmolts moving from Passmaquoddy Bay to the Bay of Fundy was inversely related to the density of aquaculture cages (DFO 1999).

Escapees and resultant interactions with native stocks are expected to continue to occur within the range of the GOM DPS given the continued operation of farms. While recent containment protocols have greatly decreased the incidence of losses from hatcheries and pens (see Section 8.4.1.16), escapes still occur. Escaped farmed fish are of great concern in Maine because, even at low numbers, they can represent a substantial portion of the returns to some rivers. Wild populations at low levels are particularly vulnerable to genetic intrusion or other disturbance caused by escapees (Hutchings 1991, DFO 1999). Modeling a range of interactions in a hypothetical small Maine river, Stevens and Cooper (2004), determined an aquaculture-derived population had the potential to supplant the wild fish.

8.5.3 Marine Survival

Natural mortality in the marine environment can be attributed to four general sources: predation, starvation, disease/parasites, and abiotic factors. While our knowledge of the marine ecology of Atlantic salmon has increased substantially in the past decade, we cannot partition total natural mortality into these categories. Consequently, investigations of natural mortality are currently based upon an examination of return rates or total marine survival. Estimates of total mortality can be made by relating either hatchery smolt stocking rates or estimates of wild smolt production to the return of adult spawners. This method integrates all natural mortality factors and, if applicable, fishing mortality. If smolts are enumerated near the marine environment, the return rate indexes only marine survival. If the smolts are enumerated as they are stocked into upstream reaches, then assessment of return rate will include outmigration mortality.

In general, returns rates for Atlantic salmon across North America have declined over the last 30 years (ICES 1998). Reported Atlantic salmon marine survival rates prior to the 1990s range from 0 to 20%, based upon a review of 20 studies by Bley and Moring (1988). A review of additional studies found that this range is realistic for Atlantic salmon survival although most return rates fall in the lower quartile of this range (Reddin 1988, Ritter 1989, Scarnecchia et al. 1989, ICES 2006). Since that reporting, marine survival rates for many southern North American monitored rivers have either remained low or continued to decline (ICES 2006). In fact, return rates have remained low even in

areas where commercial exploitation has been reduced or banned (ICES 2006) suggesting that the decline in stock status is largely due to a decline in marine survival rather than over-exploitation (Potter and Crozier 2000). These trends are consistent across the Northeast Atlantic stock complex as well (ICES 2006).

In the U.S., return rates have generally been less than 1.5%. For the period of 2001 – 2005, 2SW return rates for wild Narraguagus River smolts ranged from 0.2 to 1.2% (mean 0.7%). Returns rates for this same period from hatchery Penobscot River smolts ranged from 0.03 to 0.07% (mean 0.05%) and 0.06 to 0.17% (mean 0.12%) for 1SW and 2SW respectively (ICES 2006). These return rates are low compared to the rates observed in other predominantly 2SW populations In fact, return rates for Connecticut and Merrimack River hatchery stocks average 12% and 27% of that of the St. John River in Canada, which is one of the closest Canadian rivers to the U.S. The average Penobscot River return rate is about 89% of the St. John River average. Wild stocks and stocks returning after one sea winter typically return at higher rates (Bley and Moring 1988, ICES 2006). Lower return rates might be expected for U.S. stocks, which are primarily 2SW fish and have been the result of smolt releases for most of the restoration period. However, in a comparison to only the hatchery stocks of the St. John River, survival was still lower in these more southerly U.S. systems (Porter and Ritter 1984).

Some investigators have suggested that Atlantic salmon stocks with longer migration routes typically experience lower marine survival rates (Bley and Moring 1988) resulting in a north to south decreasing marine survival gradient in North America. The lower return rates of U.S. stocks compared to Canadian stocks may be a result of their relatively long migrations and be reflective of the geographic location of these stocks in the southern extent of the range of Atlantic salmon. It is important to note that there is also a north to south trend of decreasing smolt ages. This trend results in higher freshwater productivity in the southern extent of Atlantic salmon range that could help offset the higher marine mortality. Regardless, the decline in returns rates has been well documented in numerous populations. Marine survival rates for U.S.populations remain at historically low levels. Return rates for the Big Salmon River in the Bay of Fundy have decline from an average of 6% during 1961-1991 to 0.3% in 2002 (Gibson et al. 2004). Marine survival rates in many Newfoundland and mainland Canadian populations remain low and have also recently declined (Chaput et al. 2005).

On an interannual basis, marine survival rates can be more variable than freshwater survival rates (Potter and Crozier 2000). Reddin (1988) evaluated the freshwater (egg to smolt) and marine (smolt to spawner) survival for seven cohorts of Atlantic salmon in West Arm Brook. He found that marine survival was typically higher (5.51%) than freshwater (1.67%). However, the variation in marine survival, as measured by the coefficient of variation, was nearly four times greater in the ocean (63%) than in the stream (14%). These results were partly confounded by the fact that these stocks are exploited at sea, albeit only lightly. However, unexploited Icelandic stocks had similar variation (62%) in marine survival (Scarnecchia 1984a, Scarnecchia et al. 1989). Thus, adult production may be limited by the documented decrease in marine survival as well as its year-to-year variability.

The year-to-year variation in return rates of U.S. stocks is generally synchronous with other Atlantic salmon stocks although at lower absolute levels (Friedland et al. 1993). Recent return rates have been decreasing for several North American Atlantic salmon stocks. This suggests that while some factors distinct to the U.S. stocks may be causing low return rates, the general trend is being driven by factors that occur when the stocks are mixed. Friedland et al. (1993) documented a common pattern of return rates for five North American stocks, including the Penobscot River and Connecticut River stocks, suggesting that all of these stocks responded equally to variation in survival. This observation provides an alternate hypothesis to conventional thinking that the most significant natural mortality occurs in the river, estuary, and close to the river mouth (Larsson 1985, Hvidsten and Lund 1988). The correlations between the survival rates suggest that an important cause of mortality may act upon the stocks when they are mixed and utilizing a shared habitat. Since North American Atlantic salmon are migrating from geographically distinct rivers to common ocean feeding grounds, the likelihood that their distributions will begin to overlap increases with the length of marine residency. Thus, autumn and winter are the most likely seasons when postsmolt survival is determined. Similar recruitment cohesion has been described in other Atlantic salmon stocks and salmonine species (Scarnecchia 1984a, Koslow et al. 1987, Cohen et al. 1991). This observation indicates that factors occurring in the North Atlantic, and particularly the Labrador Sea, may be important to the survival of many Atlantic salmon stocks.

While the mechanisms responsible for determining survival are currently unknown, survival rates are likely to be a function of growth patterns. Friedland et al. (1993) found that the survival rate for the Penobscot River stock was correlated to a growth index defined by intercirculi spacing over the winter period, suggesting that the first winter at sea regulates annual recruitment. This agrees with the analyses of Reddin and Shearer (1987) and Ritter (1989). This growth index also provides insight into the relations between mortality and growth. Friedland et al. (1993) found an association between growth and survival such that in years of poor growth, a greater proportion of the stock died. When growth was higher, so was survival. This suggests that the functional relationship between growth and survival may not be a threshold phenomenon. If a threshold was necessary for survival, the sample of scales from Atlantic salmon returning to rivers would only be obtained from those fish above a critical length (Friedland et al. 1993). Thus, the specific factors that dictate Atlantic salmon growth are currently unknown.

Chaput et al. (2005) reported on the possibly of a phase shift of productivity for Atlantic salmon in the Northwest Atlantic. Strong evidence is presented which supports the occurrence of a decrease in the recruitment per spawner relationship for North American Atlantic salmon populations that likely occurred over several years in the late 1980s through early 1990s. Prior to 1989, the ratio of estimated pre-fishery abundance (PFA) of 1SW salmon off the coast of West Greenland to lagged spawners (an index of the parental stock of the PFA) ranged between 4.1 and 10.7. After 1989, this ratio decreased to between 1.2 and 3.7 PFA fish to each lagged spawner. The majority of PFA fish that escape being harvested in the West Greenland fishery are destined to return to their natal

river to spawn as 2SW the year following the fishery (Jensen 1990). The evidence presented suggests that marine survival has markedly changed in the early 1990s in addition to the dramatic change which has been documented over the past 30 years. The concept of phase (or regime) shift has previously been documented and discussed for Pacific salmon populations (Beamish et al. 1999). Chaput et al. (2005) did not speculate on the causes of this shift.

The causes behind decreased marine survival are unknown and could be caused by both biotic and abiotic processes. Friedland et al. (2005) summarized numerous studies that suggest that climate mediates marine survival for Atlantic salmon as well as other fish species. Marine mortality is critical to shaping recruitment patterns in Atlantic salmon; however, the mechanisms of this remain unknown. Chaput et al. (2005) present information related to the influx of cooler water into the Northwest Atlantic Ocean in the 1990s which resulted in an increase in abundance of cold-water species in that region. Sea surface temperature is an important feature in the marine environment which may affect salmon distribution (Saunders 1986, Reddin and Shearer 1987), production (Scarnecchia 1984a, Scarnecchia 1984b, Reddin and Shearer 1987), and survival (Friedland et al. 1993, Reddin and Friedland 1993).

Choi et al. (2004) describe the catastrophic decline and changes of the Scotian Shelf demersal fish community following massive biomass removals and a decline in groundfish productivity resulting from decadal variations in water temperature and stratification within that system. Large-scale commercial fishing activities and changes in the kinetic energy regime of the Scotian Shelf system caused by an influx of northerly low salinity water resulting in increased stratification and decreased nutrient exchange from the surface to the bottom layers. This is hypothesized to have resulted in a dramatic restructuring of the Scotian Shelf ecosystem. The effects that such large-scale ecosystem changes could have on Atlantic salmon growth and survival are currently not known.

Another major change that has occurred within the Northwestern Atlantic has been the rapid expansion of the commercial aquaculture industry. The threats caused to Atlantic salmon health survival are described in Section 8.5.2.

While these investigations provide insights into the importance of habitat for marine stock health, survival, and recovery, the mechanisms responsible are still unknown. Mortality could arise from stress, starvation, predation, disease, and perhaps, other mechanisms. Choi et al.'s (2004) outline of the complexity and dynamic nature of the causes behind some of these large-scale ecosystem changes only highlights the problems associated with attempting to focus on a single species within a complex and dynamic ecosystem. Further research investigating all aspects the marine ecosystem needs to be undertaken to begin to understand the causal mechanisms behind the decreased marine survival for Atlantic salmon in the Northwest Atlantic.

In summary, recent research has identified major decadal and seasonal events with the potential to influence postsmolt survival in Atlantic salmon. Studies have demonstrated correlations between environmental parameters and survival rates, but clear causal

relationships have yet to be determined (Potter and Crozier 2000). It appears that survival of the North American stock complex of Atlantic salmon is at least partly determined when they are concentrated during the winter months in the habitat formed at the mouth of the Labrador Sea and east of Greenland (Reddin and Shearer 1987, Friedland et al. 1993, Reddin and Friedland 1993). Until more direct observation on the marine ecology of postsmolts can be made, researchers must continue to explore available historic and contemporary datasets across the North Atlantic ecosystem to investigate the mechanisms behind this reduction in productivity and survival.

8.5.4 Ecosystem Function

Historically, the freshwater, estuarine, and marine ecosystems that Maine Atlantic salmon occupied were very different from the present-day setting (see Section 3.3 for full discussion). Abundant runs of at least 10 other native diadromous species flourished in many of Maine's salmon rivers. Several of these co-evolved species (e.g., American shad, alewife, blueback herring, sea lamprey) had spawning migrations into freshwater habitats that in large part coincided in time and space with upstream migrations of adult salmon and outmigration of salmon smolts. These resources provided a diverse forage base for native predators of fish, and annually delivered to Maine salmon rivers immense quantities of fish biomass and nutrients amassed during their habitation in the marine environment. When the juveniles of these other sea-run species outmigrated to the ocean in the fall, they completed the cycle of nutrient and bioenergetic connection between the freshwater, estuarine, and marine environments.

Large populations of other species, such as sea-run rainbow smelt, occupied lower portions of these rivers and provided rich forage for kelts making their way back to sea. Robust populations of sea lamprey migrated in the spring to the same spawning grounds as salmon might use the following fall, leaving the remains of their nest construction activities as spawning habitat foundations for salmon, and depositing their carcasses to become incorporated into the nutrient base and energy budget of these headwater aquatic communities. Abundant populations of a wide diversity of mussel species, some of which depended on salmon and other sea-run species as intermediate hosts, inhabited much of the watershed and performed valuable water filtration functions, as well as representing another rich forage resource for native predators.

Many of these historical connections among these co-evolved species and their habitats have been eliminated or severely compromised by the same environmental perturbations that have lead to the severe declines in salmon abundance. In place of a co-evolved ecosystem, large populations of non-native species flourish in the vacant niches once occupied by these native species. This likely increases predation rates, competitive interactions, disease transmission, and parasite loads. Innumerable physical and chemical changes in these co-evolved species' historical habitats continue to suppress the opportunity to restore them to some semblance of historical status.

It is unknown how significant or determinant the losses of these co-evolved counterparts, and the ecological connections among them are toward the present-day situation facing the GOM DPS. Much of this uncertainty results from the lack of comprehensive,

accurate, scientifically-based documentation of the pre-disturbance environment that the GOM DPS historically occupied. However, one key element of this presumed historical setting that has received some attention and study, especially in West Coast Pacific salmon rivers, is the nutrient cycling role that sea-run fish provide.

Gresh et al. (2000) presents a comprehensive literature and database review of historical and present day Pacific salmon runs as related to the spatial and temporal delivery and distribution of marine derived biomass and nutrients in freshwater ecosystems occupied by these anadromous species. Stockner (2003) compiles a broad assemblage of studies demonstrating how aquatic communities of the Pacific Northwest respond to changes in marine-derived nutrient imports, either as a result of historical diminishment of natural sources of this import, or a result of modern efforts to artificially restore this ecological connection until natural mechanisms can again take over that role.

More specifically, marine-origin nutrients (or artificially planted surrogates thereof) have been shown to enhance growth rates and total biomass of aquatic macroinvertebrates (e.g., Minakawa et al. 2002, Quamme and Slaney 2003), enhance the content of beneficial fatty acids and other lipid-class compounds in juvenile coho salmon (Heintz et al. 2004), and represent a significant component of the nutrient content or budget of riparian vegetation (e.g., Bilby et al. 1996, Reimchen et al. 2003, Koyama et al. 2005) and riparian zone insects (Reimchen et al. 2003). In addition, Scheuerell et al. (2005) discusses how export of nutrients by Pacific salmon smolts may interact with concurrently declining imports of marine-origin nutrient subsidies to further exacerbate overall declines in freshwater nutrient budgets, and lead to the progressive loss of inter-ecosystem cycling of productivity-limiting nutrients such as phosphorous. Scheuerell et al. (2005) further stresses the importance of explicitly considering the role of marine-derived nutrients and energy in sustaining Pacific salmon populations.

While the bulk of research into this broad and complex issue has indeed come from West Coast salmon ecosystems, the issue has not been entirely ignored in East Coast river systems where anadromous fish still occur in biologically meaningful numbers. Durbin et al. (1979) demonstrated the importance of alewives in importing and exporting base nutrients in a coastal Rhode Island Pond. Garman and Macko (1998) and MacAvoy et al. (2000) collectively demonstrated the deep infiltration of marine derived nutrients and energy (i.e., biomass) within the gross energy and nutrient budgets of coastal Virginia streams supporting annual runs of anadromous clupeids, and further demonstrated the specific importance of these subsidies to the diet and energy budgets of certain fish predator species of these coastal streams. Weng et al. (2001) describe how nutrient enrichment can facilitate Atlantic salmon recovery in a river in Quebec. Finally, similar to that presented in Scheuerell et al. (2005) for Pacific salmon, Nislow et al. (2004) discusses the down-spiraling of freshwater nutrient budgets in a Scottish Atlantic salmon river, due to smolt outmigration with inadequate concurrent adult salmon escapement (and the inadequate marine nutrient subsidies that result).

Collectively, these studies yield at least two broad insights. First, diadromous fish are a significant vector for importing marine derived nutrients and biomass into freshwater

habitats, and a portion of these imports become deeply engrained into the nutrient and energy budgets of freshwater stream communities. Second, progressive loss of this function can lead to a progressive down-spiraling of dependent aquatic life communities, and this cycle can "feed" upon itself until the biological vectors are essentially extirpated on local, then subwatershed, and then entire watershed scales.

Clearly, these findings from West Coast Pacific salmon rivers cannot be haphazardly applied to Maine Atlantic salmon rivers because of the differences in species involved and in the degree of semelparity of the salmon component of each of these systems. While many of these ecosystem-level issues in Maine salmon rivers remain untested hypotheses, the weight of the evidence suggests that co-evolved, non-salmonid sea-run species, such as alewife, blueback herring, American shad (each of which demonstrates substantial semelparity), and sea lamprey (100% semelparous) historically provided a nutrient cycling role between freshwater, estuarine, and marine habitats that closely paralleled that provided by the multi-species Pacific salmon assemblage in West Coast rivers.

Recognizing that some changes that have occurred in historical Maine salmon river ecosystems may be permanent or irreversible (e.g., presence of non-native/exotic predator, competitor and disease organisms), it is likely that restoration of at least a substantial portion of this historical co-evolved diadromous fish assemblage, and the nutrient cycling function it maintained, may be obligatory to the long-term, self-sustaining restoration of the GOM DPS. Recovery of these species specifically to target restoration of nutrient cycling, if successful, should also lead to the restoration of many of the other ecological functions (e.g., restored predator-prey relationships) identified earlier in this section and in Section 3.3.

Section 9: Conclusion

The GOM DPS meets both the discreteness and the significance criteria under the DPS Policy. Therefore, the GOM DPS (as defined in Section 6 of this Status Review) should constitute a "species" under the ESA. Abundance of the GOM DPS is presently very low. Projections provided in Section 7 of this Status Review describe the probability of the GOM DPS becoming extinct over several time horizons. While the BRT makes no specific recommendation to the Services regarding the conservation status (i.e., list as threatened, list as endangered, or do not list) of the GOM DPS, the present abundance of the species is at extremely low levels. Depending on the QET chosen, the likelihood of extinction ranges from 19% to 75% within the next 100 years even with the continuation of current levels of hatchery supplementation. Threats to the GOM DPS are outlined in Section 8. Each of the five listing factors can be linked to the present low abundance of the GOM DPS.

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Section 11: Appendices

Appendix 1. Names and locations of historic salmonid fish culture facilities in Maine. Data from Locke (1969).

Facility Name	Type of Facility	Town Location	Year First Used
John Pottie	Private, also used by State	Alna	1864
Messrs. Crockett & Holmes	Private, also used by State	Norway	1871
Spoffords Pond (Silver Lake)	Federal Hatchery	Bucksport	1872
Sebec Hatchery	Federal Hatchery	Sebec	1873
Bemis Stream	Private, also used by State	Rangeley	1873
Comm. H.O. Stanley	Private, also used by State	Dixfield	1873
Isaac Harriman	Private, also used by State	Bridgton	1873
Dr. Everleth	Private, also used by State	Waldoboro	1874
Harvey Jewell, Dobsis Club	Private, also used by State	T-5 N. D. Washington	1874
Messres. Coffin. Pembroke Iron Works	Private, also used by State	Pembroke	1874
Mr. Dillingham	Private, also used by State	Naples	1875
Oquossoc Angling Assoc.	Private, also used by State	Rangeley	1877
O.A. Dennen, Kineo House Hatchery	Private, also used by State	Kineo Twp	1879
Clarence Smith	Private, also used by State	Norway	1880
Private Hatchery	Private, also used by State	Rangeley	1880
Store on Broad Street	Private, also used by State	Bangor	1880
Benjamin Lincoln	Private, also used by State	Dennysville	1882
A. J. Darling	Private, also used by State	Enfield	1883
Ede's Falls	Private, also used by State	Naples	1885
Private Hatchery	Private, also used by State	Weld	1885
Lake Auburn Fish Prot. Assoc	Private, also used by State	Auburn	1889
Green Lake Station Hatchery	Federal Hatchery	Dedham	1892
Private Hatchery	Private, also used by State	Caribou	1892
Swan Lake Hatchery	Private, also used by State	Swanville	1893
Big Island Hatchery	Private, also used by State	T-3 R-5	1895
Commodore Club	Private, also used by State	Hartland	1895
Kennebec Assn. Hatchery	Private, also used by State	Belgrade	1895
King and Bartlett Hatchery	Private, also used by State	T-4 R-5	1895
Auburn Hatchery	State Hatchery	Auburn	1895
Caribou Hatchery	State Hatchery	Caribou	1895
Megantic Club Hatchery	Private, also used by State	T-2 R-6	1896
Parmachenee Club Hatchery	Private, also used by State	T-5 R-4, Franklin	1896

Facility Name	Type of Facility	Town Location	Year First Used
S.S. Crafts	Private, also used by State	Monson	1896
Monmouth Hatchery	State Hatchery	Monmouth	1896
Sebago (Ede's Falls) Hatchery	State Hatchery	Naples	1896
Carlton Brook Feeding Station	State Feeding Station	Winthrop	1901
Moosehead Hatchery	State Hatchery	T-2 R-6	1901
Little Spring Brook Hatchery	Federal Hatchery	T-4 R-8	1903
Sebago Hatchery	State Hatchery	Raymond	1903
Belgrade Hatchery	State Hatchery	Belgrade	1906
Lake Moxie Hatchery (The Forks)	State Hatchery	Moxie Gore	1907
W. H. Rowe	Private Commercial	Cumberland	1908
Knox County Hatchery	State Hatchery	Camden	1909
B.G. Donnell	Private Commercial	York	1910
Clear Springs Hatchery (Rowe)	Private Commercial	Hollis	1910
Tunk Lake Hatchery	State Hatchery	T10 SD	1910
Dead River Hatchery	State Hatchery	Eustis	1913
Mountain View Feeding Station	State Feeding Station	Rangeley	1920
Shin Pond Feeding Station	State Feeding Station	Mt. Chase	1925
Gorham Feeding Station	State Feeding Station	Gorham	1926
Jackman Feeding Station	State Feeding Station	Jackman	1928
Houlton Feeding Station	State Feeding Station	Houlton	1929
Turner Feeding Station	State Feeding Station	Turner	1929
Littleton Hatchery	State Hatchery	Littleton	1929
Head Tide Feeding Station	State Feeding Station	Alna	1930
Hollis Feeding Station	State Feeding Station	Hollis	1930
Lily Bay Feeding Station	State Feeding Station	TA R-14 Wels	1930
Appleton Feeding Station	State Feeding Station	Appleton	1931
Caratunk Feeding Station	State Feeding Station	Embden	1931
LaGrange Feeding Station	State Feeding Station	LaGrange	1931
Newport Feeding Station	State Feeding Station	Newport	1931
Norridgewock Feeding Station	State Feeding Station	Norridgewock	1932
Rangeley Feeding Station	State Feeding Station	Rangeley	1932
Rumford Feeding Station	State Feeding Station	Rumford	1932
Kokadjo Feeding Station	State Feeding Station	T1 R13 Wels	1936
Birch River Feeding Station	State Feeding Station	Winterville	1938
Lovell Feeding Station	State Feeding Station	Lovell	1938
Salem Feeding Station	Federal Feeding Station	Salem Twp	1941
Dead River Hatchery	State Hatchery	Pierce Pond Twp	1946

Facility Name	Type of Facility	Town Location	Year First Used
Deblois Hatchery	State & Private Hatchery	Deblois	1947
Lovell Bass Pools	State Feeding Station	Lovell	1950
Union River Sportsman Club*	Private Feeding Station	Ellsworth	2002
Cherryfield Feeding Station	State Feeding Station	Cherryfield	unk.
Machias Feeding Station	State Feeding Station	Machias	unk.
Presque Isle Feeding Station	State Feeding Station	Presque Isle	unk.

* Data not from Locke (1969). This facility received Penobscot River domestic Atlantic salmon eggs from Green Lake National Fish Hatchery, but they have not successfully released fish.

Appendix 2. Name and town location of existing (2004-2005) Atlantic salmon fish culture facilities in Maine.

Facility Name	Type of Facility	Town Location	Year First Used	Type of *S. salar* broodstock propogated or reared
Bingham	Aquaculture	Bingham	unk.	Aquaculture
Gardner Lake	Aquaculture	East Machias	1991	Aquaculture
Oquossoc	Aquaculture	Rangeley	1986	Aquaculture
Craig Brook	Federal Hatchery	Orland	1871	Sea-run, Captive
Green Lake	Federal Hatchery	Ellsworth	1974	Captive, Sea-run, Domestic
Downeast Salmon Federation	Private Feeding Station	Columbia Falls	1992	Captive
Dug Brook	Private Feeding Station	Ashland	2002	St. John Stock
Pine Tree	Private Feeding Station	Sanford	1980	Domestic
Saco River Salmon Club	Private Feeding Station	Saco	1997	Domestic
U.S. Dept. Agriculture	Research Facility	Franklin	2004	Sea-run
Univ. of Maine	Research Facility	Orono	2003	Sea-run, Captive
Embden	State Feeding Station	Embden	1956	Landlock
Casco	State Hatchery	Casco	1955	Landlock
Enfield	State Hatchery	Enfield	1909	Landlock
Grand Lake Stream	State Hatchery	Grand Lake Strm.	1936	Landlock

Appendix 3. Summary of sea-run Atlantic salmon fry and parr stocking for 26 rivers in Maine from 1871 to 2003. Fry/parr origin code: D = Dennys; EM = East Machias; M = Machias; N = Narraguagus; NB = New Brinswick; ON = Ontario; P = Penobscot; PL = Pleasant; Q = Quebec; SC = St. Croix; SJ = St. John; U = Union; ? = unknown. Note: St. John River has three drainages listed separately- Upper St. John, Aroostook, and Meduxnekeag. Data Source1= Baum (1997), 2= USASAC (1996-2004).

River	Year Stocked	Fry (#)	Fry Origin	Age 0 Parr	Age 0 Parr Origin	Age 1 Parr	Age 1 Parr Origin	Total Parr	Data Source
Androscoggin	1872	20,000	P					20,000	1
Androscoggin	1873	130,000	P					130,000	1
Androscoggin	1874	95,830	P					95,830	1
Androscoggin	1875	50,870	P					50,870	1
Androscoggin	2001	3,000	P?					3,000	2
Androscoggin	2003	1,000	P?					1,000	2
Aroostook	1895	144,740	P					144,740	1
Aroostook	1896	146,645	P					146,645	1
Aroostook	1927					80,000	Q	80,000	1
Aroostook	1928					80,000	Q	80,000	1
Aroostook	1929					40,000	Q	40,000	1
Aroostook	1931					50,000	NB	50,000	1
Aroostook	1940			10,000	D			10,000	1
Aroostook	1951			20,065	NB			20,065	1
Aroostook	1952			20,100	NB			20,100	1
Aroostook	1954			48,600	NB			48,600	1
Aroostook	1955			70,095	NB			70,095	1
Aroostook	1956			75,130	NB			75,130	1
Aroostook	1957			19,500	NB			19,500	1
Aroostook	1958			69,850	NB			69,850	1
Aroostook	1959					73,500	NB	73,500	1
Aroostook	1960					96,450	NB	96,450	1
Aroostook	1961					37,400	NB	37,400	1
Aroostook	1979			3,100	P			3,100	1
Aroostook	1981			25,150	P	20,450	P	45,600	1
Aroostook	1985					1,850	P	1,850	1
Aroostook	1986	84,000	P					84,000	1
Aroostook	1987	41,400	SJ					41,400	1
Aroostook	1988	43,300	SJ					43,300	1
Aroostook	1989	312,600	SJ					312,600	1
Aroostook	1989			14,750	P			14,750	1
Aroostook	1990	68,600	SJ					68,600	1

River	Year Stocked	Fry (#)	Fry Origin	Age 0 Parr	Age 0 Parr Origin	Age 1 Parr	Age 1 Parr Origin	Total Parr	Data Source
Aroostook	1991	74,500	SJ					74,500	1
Aroostook	1992					16,350	SJ	16,350	1
Aroostook	1995	4,300	SJ					4,300	1
Aroostook	1997	578,000	?					578,000	2
Aroostook	1998	142,000	?					142,000	2
Aroostook	1999	163,000	?					163,000	2
Aroostook	2001	182,000	?	300				182,300	2
Aroostook	2002	122,000	?					122,000	2
Aroostook	2003	138,000	?					138,000	2
Boyden	1875	20,300	p					20,300	1
Dennys	1875	20,000	P					20,000	1
Dennys	1881	3,900	P					3,900	1
Dennys	1883	20,000	P					20,000	1
Dennys	1884	39,500	P					39,500	1
Dennys	1885	36,000	P					36,000	1
Dennys	1888	36,000	P					36,000	1
Dennys	1889	36,000	P					36,000	1
Dennys	1918	21,000	P					21,000	1
Dennys	1919	627,000	P					627,000	1
Dennys	1920	437,500	P					437,500	1
Dennys	1922	550,000	NB					550,000	1
Dennys	1923	194,000	NB			40,000	NB	234,000	1
Dennys	1924	179,200	NB					179,200	1
Dennys	1925	112,500	NB					112,500	1
Dennys	1925	225,000	Q					225,000	1
Dennys	1926	5,000	NB					5,000	1
Dennys	1926	70,000	Q					70,000	1
Dennys	1927	100,500	NB					100,500	1
Dennys	1928	100,500	NB					100,500	1
Dennys	1936	360,000	NB					360,000	1
Dennys	1937					30,000	NB	30,000	1
Dennys	1942			6,000	P			6,000	1
Dennys	1943			7,000	P	4,150	M	11,150	1
Dennys	1944					9,000	P	9,000	1
Dennys	1949			5,005	P			5,005	1
Dennys	1950			9,955	M+N			9,955	1
Dennys	1951			10,225	NB			10,225	1
Dennys	1952			20,000	NB			20,000	1
Dennys	1954			51,150	NB	19,530	NB	70,680	1

River	Year Stocked	Fry (#)	Fry Origin	Age 0 Parr	Age 0 Parr Origin	Age 1 Parr	Age 1 Parr Origin	Total Parr	Data Source
Dennys	1955			50,455	NB			50,455	1
Dennys	1956			45,915	NB			45,915	1
Dennys	1957			9,900	NB			9,900	1
Dennys	1958			9,850	NB			9,850	1
Dennys	1960			19,900	NB			19,900	1
Dennys	1960			28,000	M			28,000	1
Dennys	1960					47,500	NB	47,500	1
Dennys	1961			20,350	NB			20,350	1
Dennys	1962			41,450	NB			41,450	1
Dennys	1966					15,750	NB	15,750	1
Dennys	1966					28,015	M	28,015	1
Dennys	1975					3,000	P	3,000	1
Dennys	1976			8,250	P			8,250	1
Dennys	1983	20,020	P					20,020	1
Dennys	1986			8,255	PU			8,255	1
Dennys	1987	24,000	P					24,000	1
Dennys	1988	29,900	P					29,900	1
Dennys	1989	11,900	P					11,900	1
Dennys	1990	20,200	P					20,200	1
Dennys	1991	25,200	P			400	P	25,600	1
Dennys	1993	32,700	D					32,700	1
Dennys	1994	20,000	D					20,000	1
Dennys	1995	84,000	D					84,000	1
Dennys	1996	142,000	D					142,000	2
Dennys	1997	213,000	D					213,000	2
Dennys	1998	233,000	D	10,400	D			243,400	2
Dennys	1999	172,000	D	3,000	D			175,000	2
Dennys	2000	96,000	D	30,500	D			126,500	2
Dennys	2001	59,000	D	16,500	D	1,400	D	76,900	2
Dennys	2002	84,000	D	33,000	D	1,900	D	118,900	2
Dennys	2003	133,000	D	30,400	D	600	D	164,000	2
Ducktrap	1985	15,000	P					15,000	1
Ducktrap	1986	8,000	P					8,000	1
Ducktrap	1987	15,000	P					15,000	1
Ducktrap	1988	10,150	P					10,150	1
Ducktrap	1989	17,040	P					17,040	1
Ducktrap	1990	17,500	P					17,500	1
East Machias	1917	30,000	P					30,000	1
East Machias	1940			7,000	D			7,000	1

River	Year Stocked	Fry (#)	Fry Origin	Age 0 Parr	Age 0 Parr Origin	Age 1 Parr	Age 1 Parr Origin	Total Parr	Data Source
East Machias	1982					8,685	P	8,685	1
East Machias	1985	12,520	P					12,520	1
East Machias	1986	7,500	P					7,500	1
East Machias	1987	10,000	P					10,000	1
East Machias	1988	10,000	P			7,500	P	17,500	1
East Machias	1989	29,900	P	6,545	P	8,000	P	44,445	1
East Machias	1990	42,000	P			10,055	P	52,055	1
East Machias	1991	26,600	P			8,295	P	34,895	1
East Machias	1996	115,000	EM					115,000	2
East Machias	1997	113,000	EM					113,000	2
East Machias	1998	190,000	EM					190,000	2
East Machias	1999	210,000	EM	1,000	EM			211,000	2
East Machias	2000	197,000	EM					197,000	2
East Machias	2001	242,000	EM					242,000	2
East Machias	2002	236,000	EM					236,000	2
East Machias	2003	314,000	EM					314,000	2
Kennebec	1881	87,460	P					87,460	1
Kennebec	2001	3,000	P					3,000	2
Kennebec	2002	7,000	P					7,000	2
Kennebec	2003	42,000	P					42,000	2
Kennebunk	1913	10,000	P					10,000	1
Little Falls (Hobart)	1947					35,370	P	35,370	1
Little Falls (Hobart)	1948			7,035	P	11,725	M	18,760	1
Little Falls (Hobart)	1949			6,140	M	2,310	P	8,450	1
Little Falls (Hobart)	1950			10,770	M, N	6,010	NB	16,780	1
Little Falls (Hobart)	1951			11,905	NB			11,905	1
Little Falls (Hobart)	1952	6,680	NB	13,335	NB	9,980	NB	29,995	1
Little Falls (Hobart)	1953	6,660	NB	13,215	NB	7,455	NB	27,330	1
Little Falls (Hobart)	1954			20,040	NB	11,620	NB	31,660	1
Machias	1875	1,000	P					1,000	1
Machias	1881	25,000	?					25,000	1
Machias	1882	29,800	P					29,800	1
Machias	1883	17,450	P					17,450	1
Machias	1922	50,000	NB					50,000	1
Machias	1941			20,000	P			20,000	1
Machias	1942			34,000	P			34,000	1
Machias	1943			5,000	P			5,000	1
Machias	1943					16,000	M	16,000	1
Machias	1947					38,810	P	38,810	1

River	Year Stocked	Fry (#)	Fry Origin	Age 0 Parr	Age 0 Parr Origin	Age 1 Parr	Age 1 Parr Origin	Total Parr	Data Source
Machias	1948					43,100	M	43,100	1
Machias	1949			25,000	NB			25,000	1
Machias	1949			24,835	M			24,835	1
Machias	1949					7,320	P	7,320	1
Machias	1950	100,150	M,N	29,500	M,N			129,650	1
Machias	1950					17,030	M	17,030	1
Machias	1951					45,710	M,P	45,710	1
Machias	1952					22,430	NB	22,430	1
Machias	1953			43,930	NB			43,930	1
Machias	1957			19,485	NB			19,485	1
Machias	1958			17,440	NB			17,440	1
Machias	1958			17,525	M			17,525	1
Machias	1959			15,565	NB			15,565	1
Machias	1959			30,365	M			30,365	1
Machias	1960			27,670	NB			27,670	1
Machias	1960			29,795	M			29,795	1
Machias	1961			2,035	M			2,035	1
Machias	1961			2,035	NB			2,035	1
Machias	1962			30,575	NB			30,575	1
Machias	1962			30,995	M			30,995	1
Machias	1964					7,080	M	7,080	1
Machias	1982			12,025	P			12,025	1
Machias	1983			505	U			505	1
Machias	1985					7,000	P	7,000	1
Machias	1986	7,500	P	8,000	P			15,500	1
Machias	1987					2,090	U	2,090	1
Machias	1987			12,510	P	10,235	P	22,745	1
Machias	1988					765	U	765	1
Machias	1988	30,200	P			30,695	P	60,895	1
Machias	1989	48,550	P	13,785	P	28,000	P	90,335	1
Machias	1990	75,000	P	10,130	P	17,630	P	102,760	1
Machias	1991	13,000	P	30,000	P	21,405	P	64,405	1
Machias	1992	13,790	?					13,790	1
Machias	1994	49,970	M					49,970	1
Machias	1995	150,000	M					150,000	1
Machias	1996	233,000	M					233,000	2
Machias	1997	236,000	M					236,000	2
Machias	1998	300,000	M	5,900	M			305,900	2
Machias	1999	169,000	M	1,000	M			170,000	2

River	Year Stocked	Fry (#)	Fry Origin	Age 0 Parr	Age 0 Parr Origin	Age 1 Parr	Age 1 Parr Origin	Total Parr	Data Source
Machias	2000	209,000	M					209,000	2
Machias	2001	267,000	M					267,000	2
Machias	2002	327,000	M					327,000	2
Machias	2003	341,000	M	300	M			341,300	2
Medomak	1874	38,000	P					38,000	1
Medomak	1875	5,000	P					5,000	1
Meduxnekeag	1926	92,000	Q					92,000	1
Meduxnekeag	1927	92,000	Q					92,000	1
Meduxnekeag	1929					40,000	Q	40,000	1
Meduxnekeag	1931					50,000	NB	50,000	1
Meduxnekeag	1979			2,100	?			2,100	1
Narraguagus	1918	225,000	P					225,000	1
Narraguagus	1919	437,500	P					437,500	1
Narraguagus	1924	64,000	NB					64,000	1
Narraguagus	1925	60,000	NB					60,000	1
Narraguagus	1926	50,000	Q					50,000	1
Narraguagus	1927	100,500	NB					100,500	1
Narraguagus	1928	10,500	NB					10,500	1
Narraguagus	1928	90,000	Q					90,000	1
Narraguagus	1929	88,725	NB					88,725	1
Narraguagus	1931					25,000	NB	25,000	1
Narraguagus	1936	85,000	NB					85,000	1
Narraguagus	1941			20,000	P			20,000	1
Narraguagus	1942			10,000	P			10,000	1
Narraguagus	1943			12,500	P	5,000	M	17,500	1
Narraguagus	1944					9,000	P	9,000	1
Narraguagus	1949	29,280	NB					29,280	1
Narraguagus	1950	35,000	M+N	9,855	M+N			44,855	1
Narraguagus	1951			14,990	M+P			14,990	1
Narraguagus	1951			20,335	M+N			20,335	1
Narraguagus	1951			14,980	NB	50,300	NB	65,280	1
Narraguagus	1952			78,565	NB	48,235	NB	126,800	1
Narraguagus	1953			42,250	NB	99,335	NB	141,585	1
Narraguagus	1955			39,860	NB			39,860	1
Narraguagus	1956			48,725	NB			48,725	1
Narraguagus	1957			29,640	NB			29,640	1
Narraguagus	1958			19,905	NB			19,905	1
Narraguagus	1959			19,030	NB			19,030	1
Narraguagus	1960			32,395	NB			32,395	1

River	Year Stocked	Fry (#)	Fry Origin	Age 0 Parr	Age 0 Parr Origin	Age 1 Parr	Age 1 Parr Origin	Total Parr	Data Source
Narraguagus	1961			17,065	NB			17,065	1
Narraguagus	1964			20,075	N			20,075	1
Narraguagus	1964					5,335	NB	5,335	1
Narraguagus	1965			20,025	M			20,025	1
Narraguagus	1966			30,125	N			30,125	1
Narraguagus	1983			7,790	P			7,790	1
Narraguagus	1985	10,280	P					10,280	1
Narraguagus	1987	15,105	P					15,105	1
Narraguagus	1988			3,490	U	1,115	U	4,605	1
Narraguagus	1988	20,000	P	9,545	P	4,440	P	33,985	1
Narraguagus	1989	29,260	P	9,500	P	7,000	P	45,760	1
Narraguagus	1995	105,000	N					105,000	1
Narraguagus	1996	196,000	N					196,000	2
Narraguagus	1997	209,000	N			2,000	N	211,000	2
Narraguagus	1998	274,000	N	14,400	N			288,400	2
Narraguagus	1999	155,000	N	18,200	N			173,200	2
Narraguagus	2000	252,000	N					252,000	2
Narraguagus	2001	353,000	N					353,000	2
Narraguagus	2002	261,000	N					261,000	2
Narraguagus	2003	491,000	N					491,000	2
Orland	1889	19,000	P			13,960	P	32,960	1
Orland	1891					103,510	P	103,510	1
Orland	1893	84,000	P					84,000	1
Orland	1943					2,290	NB	2,290	1
Orland	1945					600	P	600	1
Orland	1949	10,085	NB					10,085	1
Orland	1950	9,895	M+N					9,895	1
Orland	1967					7,640	O	7,640	1
Pennamaquan	1873	8,610	P					8,610	1
Pennamaquan	1874	45,000	P					45,000	1
Pennamaquan	1918	375,000	P					375,000	1
Penobscot	1873	67,000	P					67,000	1
Penobscot	1874	210,000	P					210,000	1
Penobscot	1875	354,900	P					354,900	1
Penobscot	1881	147,000	P					147,000	1
Penobscot	1882	297,000	P					297,000	1
Penobscot	1883	195,000	P					195,000	1
Penobscot	1884	688,000	P					688,000	1
Penobscot	1885	234,000	P					234,000	1

River	Year Stocked	Fry (#)	Fry Origin	Age 0 Parr	Age 0 Parr Origin	Age 1 Parr	Age 1 Parr Origin	Total Parr	Data Source
Penobscot	1891					103,510	P	103,510	1
Penobscot	1892					254,200	P	254,200	1
Penobscot	1897	1,345,700	P			19,250	P	1,364,950	1
Penobscot	1898	1,482,500	P			25,160	P	1,507,660	1
Penobscot	1899	445,000	P			150,610	P	595,610	1
Penobscot	1900	908,070	P					908,070	1
Penobscot	1901			282,400	P	171,620	P	454,020	1
Penobscot	1902	48,715	P			277,000	P	325,715	1
Penobscot	1903	1,193,000	P			299,120	P	1,492,120	1
Penobscot	1904	2,566,720	P			369,000	P	2,935,720	1
Penobscot	1905	727,460	P			289,100	P	1,016,560	1
Penobscot	1906	1,897,610	P			79,200	P	1,976,810	1
Penobscot	1907	2,156,850	P			39,830	P	2,196,680	1
Penobscot	1908	2,079,510	P			30,000	P	2,109,510	1
Penobscot	1909	647,790	P			24,430	P	672,220	1
Penobscot	1910	1,217,370	P			232,910	P	1,450,280	1
Penobscot	1911	2,854,080	P					2,854,080	1
Penobscot	1912	1,820,350	P					1,820,350	1
Penobscot	1913	3,482,460	P					3,482,460	1
Penobscot	1914	2,546,290	P					2,546,290	1
Penobscot	1915	1,804,310	P					1,804,310	1
Penobscot	1916	1,709,810	P					1,709,810	1
Penobscot	1917	2,977,850	P					2,977,850	1
Penobscot	1918	1,350,000	P					1,350,000	1
Penobscot	1919	1,025,000	P					1,025,000	1
Penobscot	1920	628,530	P					628,530	1
Penobscot	1920	921,470	NB					921,470	1
Penobscot	1921	565,760	NB					565,760	1
Penobscot	1921	821,240	P					821,240	1
Penobscot	1922	262,480	NB					262,480	1
Penobscot	1922	471,520	P					471,520	1
Penobscot	1923	257,000	NB					257,000	1
Penobscot	1924	250,800	NB					250,800	1
Penobscot	1925	243,000	Q					243,000	1
Penobscot	1925	657,000	NB					657,000	1
Penobscot	1926	256,000	Q					256,000	1
Penobscot	1926	419,640	NB					419,640	1
Penobscot	1927	258,500	Q					258,500	1
Penobscot	1927	599,500	NB					599,500	1

River	Year Stocked	Fry (#)	Fry Origin	Age 0 Parr	Age 0 Parr Origin	Age 1 Parr	Age 1 Parr Origin	Total Parr	Data Source
Penobscot	1928	772,000	NB					772,000	1
Penobscot	1929					103,975	NB	103,975	1
Penobscot	1930					88,800	NB	88,800	1
Penobscot	1931	679,500	NB			215,000	NB	894,500	1
Penobscot	1932					4,100	P	4,100	1
Penobscot	1932	488,000	NB			27,330	NB	515,330	1
Penobscot	1933	400,000	NB	4,700	NB			404,700	1
Penobscot	1935					179,000	NB	179,000	1
Penobscot	1936	25,000	NB			118,000	NB	143,000	1
Penobscot	1937					40,500	NB	40,500	1
Penobscot	1941	112,500	P					112,500	1
Penobscot	1941					63,500	D	63,500	1
Penobscot	1942			25,030	M	15,000	P	40,030	1
Penobscot	1943					9,165	MN	9,165	1
Penobscot	1944					50,940	P	50,940	1
Penobscot	1945					51,775	P	51,775	1
Penobscot	1946					25,355	P	25,355	1
Penobscot	1947					70,465	P	70,465	1
Penobscot	1948			61,000	P			61,000	1
Penobscot	1949			30,245	NB			30,245	1
Penobscot	1949					33,000	P	33,000	1
Penobscot	1950					19,605	NB	19,605	1
Penobscot	1950			29,545	M+M	19,605	MN	49,150	1
Penobscot	1954			68,315	NB	33,350	NB	101,665	1
Penobscot	1955			68,490	NB			68,490	1
Penobscot	1956			79,310	NB			79,310	1
Penobscot	1957			90,030	NB			90,030	1
Penobscot	1958			42,385	NB			42,385	1
Penobscot	1959			50,595	NB			50,595	1
Penobscot	1965					26,210	MN	26,210	1
Penobscot	1967					21,915	NB	21,915	1
Penobscot	1968					25,000	MN	25,000	1
Penobscot	1970			10,000	N			10,000	1
Penobscot	1970			15,000	MN			15,000	1
Penobscot	1971					15,800	N	15,800	1
Penobscot	1972	129,000	M					129,000	1
Penobscot	1974					9,085	PN	9,085	1
Penobscot	1974					35,100	P	35,100	1
Penobscot	1975			8,200	P	12,300	P	20,500	1

River	Year Stocked	Fry (#)	Fry Origin	Age 0 Parr	Age 0 Parr Origin	Age 1 Parr	Age 1 Parr Origin	Total Parr	Data Source
Penobscot	1976					83,850	P	83,850	1
Penobscot	1978					126,750	P	126,750	1
Penobscot	1979	28,775	U					28,775	1
Penobscot	1979			65,950	P			65,950	1
Penobscot	1981	201,780	P	25,350	P	50,255	P	277,385	1
Penobscot	1982			35,855	U			35,855	1
Penobscot	1982	248,150	P	15,075	P			263,225	1
Penobscot	1982					206,430	?	206,430	1
Penobscot	1983					12,580	P	12,580	1
Penobscot	1983					19,345	U	19,345	1
Penobscot	1984			15,570	U			15,570	1
Penobscot	1984	80,050	P	18,795	P			98,845	1
Penobscot	1985			33,050	U	6,240	U	39,290	1
Penobscot	1985	196,840	P	26,400	P	11,375	P	234,615	1
Penobscot	1986					410	U	410	1
Penobscot	1986	225,750	P	25,705	P	50,970	P	302,425	1
Penobscot	1987			11,995	U	16,940	U	28,935	1
Penobscot	1987	33,115	P	46,140	P	84,140	P	163,395	1
Penobscot	1988	431,040	P					431,040	1
Penobscot	1989			21,780	U	11,030	U	32,810	1
Penobscot	1989	76,985	P	82,315	P	68,545	P	227,845	1
Penobscot	1990	10,350	U+P			3,510	U	13,860	1
Penobscot	1990	306,825	P	166,450	P	151,770	P	625,045	1
Penobscot	1991	398,450	P	202,600	P	104,140	P	705,190	1
Penobscot	1992	925,350	P	278,200	P	106,650	P	1,310,200	1
Penobscot	1993	1,320,295	P	202,300	P	9,560	P	1,532,155	1
Penobscot	1994	949,000	P			2,400	P	951,400	2
Penobscot	1995	502,000	P	325,000	P	5,600	P	832,600	2
Penobscot	1996	1,242,000	P	226,000	P	17,500	P	1,485,500	2
Penobscot	1997	1,472,000	P	310,900	P	4,200	P	1,787,100	2
Penobscot	1998	930,000	P	337,400	P	13,400	P	1,280,800	2
Penobscot	1999	1,498,000	P	229,600	P	1,500	P	1,729,100	2
Penobscot	2000	513,000	P	288,800	P	700	P	802,500	2
Penobscot	2001	364,000	P	235,800	P	2,100	P	601,900	2
Penobscot	2002	746,000	P	396,700	P	1,800	P	1,144,500	2
Penobscot	2003	741,000	P	320,700	P	2,100	P	1,063,800	2
Pleasant	1919	437,500	P					437,500	1
Pleasant	1950			10,005	M+N			10,005	1
Pleasant	1954			10,065	NB			10,065	1

River	Year Stocked	Fry (#)	Fry Origin	Age 0 Parr	Age 0 Parr Origin	Age 1 Parr	Age 1 Parr Origin	Total Parr	Data Source
Pleasant	1955			10,000	NB			10,000	1
Pleasant	1957			9,030	NB			9,030	1
Pleasant	1958			9,815	NB			9,815	1
Pleasant	1963					11,280	NB	11,280	1
Pleasant	1964					4,595	MN	4,595	1
Pleasant	1965					26,940	NB	26,940	1
Pleasant	1985	33,000	P					33,000	1
Pleasant	1986	25,000	P					25,000	1
Pleasant	1987	25,015	P					25,015	1
Pleasant	1988	25,000	P			1,800	P	26,800	1
Pleasant	1989	26,195	P	2,500	P			28,695	1
Pleasant	1990	30,170	P					30,170	1
Pleasant	1991	23,000	P					23,000	1
Pleasant	2002			13,500	PL			13,500	2
Pleasant	2003	82,000	PL					82,000	2
Presumscot	1875	40,000	P					40,000	1
Presumscot	1881	92,000	P					92,000	1
Saco	1881	35,000	P					35,000	1
Saco	1982			2,355	P			2,355	1
Saco	1982			44,745	U			44,745	1
Saco	1985					23,600	P	23,600	1
Saco	1986					10,005	P	10,005	1
Saco	1987					69,825	P	69,825	1
Saco	1988	47,160	P					47,160	1
Saco	1989			37,760	P	48,550	P	86,310	1
Saco	1990			30,115	P	47,830	P	77,945	1
Saco	1991	111,000	P					111,000	1
Saco	1992	153,600	P	50,205	P	425	P	204,230	1
Saco	1993	166,500	P					166,500	1
Saco	1994	190,355	P					190,355	1
Saco	1995	376,000	P					376,000	1
Saco	1996			45,000	P			45,000	2
Saco	1997	97,000	P	63,300	P			160,300	2
Saco	1998	429,000	P	50,000	P			479,000	2
Saco	1999	688,000	P	47,000	P			735,000	2
Saco	2000	599,000	P	48,200	P			647,200	2
Saco	2001	479,000	P					479,000	2
Saco	2002	597,000	P					597,000	2
Saco	2003	501,000	P	20,000	P			521,000	2

River	Year Stocked	Fry (#)	Fry Origin	Age 0 Parr	Age 0 Parr Origin	Age 1 Parr	Age 1 Parr Origin	Total Parr	Data Source
Sheepscot	1871					1,500	ON	1,500	1
Sheepscot	1948			12,000	P			12,000	1
Sheepscot	1949			10,200	NB			10,200	1
Sheepscot	1949					8,240	P	8,240	1
Sheepscot	1950			19,800	M+N			19,800	1
Sheepscot	1950					20,200	NB	20,200	1
Sheepscot	1951			10,010	NB			10,010	1
Sheepscot	1952			20,000	NB			20,000	1
Sheepscot	1954			29,400	NB			29,400	1
Sheepscot	1955			19,890	NB			19,890	1
Sheepscot	1956			19,320	NB			19,320	1
Sheepscot	1957			14,955	NB			14,955	1
Sheepscot	1958			20,180	NB			20,180	1
Sheepscot	1960			27,050	NB	36,960	NB	64,010	1
Sheepscot	1961			24,220	NB			24,220	1
Sheepscot	1962			15,500	NB	32,845	NB	48,345	1
Sheepscot	1964					6,175	Q	6,175	1
Sheepscot	1985	20,080	P					20,080	1
Sheepscot	1986			6,570	U			6,570	1
Sheepscot	1986	100,150	P	5,000	P			105,150	1
Sheepscot	1987	15,060	P	8,240	P			23,300	1
Sheepscot	1988			2,515	U			2,515	1
Sheepscot	1988	40,040	P	9,740	P			49,780	1
Sheepscot	1989	28,500	P	13,640	P	10,000	P	52,140	1
Sheepscot	1990	27,070	P	10,070	P	10,000	P	47,140	1
Sheepscot	1991	18,000	P	15,000	P	645	P	33,645	1
Sheepscot	1996	102,000	S					102,000	2
Sheepscot	1997	64,000	S					64,000	2
Sheepscot	1998	256,000	S	9,300	S			265,300	2
Sheepscot	1999	302,000	S	4,700	S			306,700	2
Sheepscot	2000	211,000	S					211,000	2
Sheepscot	2001	171,000	S					171,000	2
Sheepscot	2002	172,000	S					172,000	2
Sheepscot	2003	323,000	S					323,000	2
Somesville	1950	14,795	M+N					14,795	1
Somesville	1951			4,990	NB			4,990	1
Somesville	1952			5,145	NB			5,145	1
Somesville	1954					4,970	NB	4,970	1
St. Croix	1873	10,000	P					10,000	1

River	Year Stocked	Fry (#)	Fry Origin	Age 0 Parr	Age 0 Parr Origin	Age 1 Parr	Age 1 Parr Origin	Total Parr	Data Source
St. Croix	1874	22,000	P					22,000	1
St. Croix	1875	20,000	P					20,000	1
St. Croix	1897	150,000	P					150,000	1
St. Croix	1898	137,500	P					137,500	1
St. Croix	1925	112,500	NB					112,500	1
St. Croix	1926	101,000	NB					101,000	1
St. Croix	1927	150,000	NB					150,000	1
St. Croix	1928	100,500	NB					100,500	1
St. Croix	1940			5,000	D			5,000	1
St. Croix	1949			101,000	NB			101,000	1
St. Croix	1966					43,920	N	43,920	1
St. Croix	1967			8,975	NB			8,975	1
St. Croix	1968					5,070	NB	5,070	1
St. Croix	1969					25,000	M	25,000	1
St. Croix	1982			3,750	U	47,435	U	51,185	1
St. Croix	1982	101,000	U	17,150	P	2,605	P	120,755	1
St. Croix	1983					11,045	U	11,045	1
St. Croix	1983					14,445	P	14,445	1
St. Croix	1984	54,070	P			13,800	P	67,870	1
St. Croix	1985	177,740	P	46,440	P	12,900	U	237,080	1
St. Croix	1986	193,000	P					193,000	1
St. Croix	1987					15,015	U	15,015	1
St. Croix	1987	255,500	P			25,975	P	281,475	1
St. Croix	1990	254,900	?					254,900	1
St. Croix	1991	51,025	?					51,025	1
St. Croix	1991			40,000	P			40,000	1
St. Croix	1992			56,545	P	14,880	P	71,425	1
St. Croix	1992	85,305	?					85,305	1
St. Croix	1993			100,950	P			100,950	1
St. Croix	1994	87,000	?	38,600	?			125,600	2
St. Croix	1995	1,000	P					1,000	2
St. Croix	1996			52,100	?			52,100	2
St. Croix	1997	1,000	P					1,000	2
St. Croix	1997			400	?			400	2
St. Croix	1998			31,700	?	200	?	31,900	2
St. Croix	1998	2,000	P					2,000	2
St. Croix	1999	1,000	P					1,000	2
St. Croix	1999			22,500	?			22,500	2
St. Croix	2000	1,000	P					1,000	2

River	Year Stocked	Fry (#)	Fry Origin	Age 0 Parr	Age 0 Parr Origin	Age 1 Parr	Age 1 Parr Origin	Total Parr	Data Source
St. Croix	2000			19,000	?			19,000	2
St. Croix	2001	1,000	P					1,000	2
St. Croix	2001			6,300	?			6,300	2
St. Croix	2002	1,000	P					1,000	2
St. Croix	2002			15,400	?			15,400	2
St. Croix	2003	1,000	P	16,800				17,800	2
St. George	1873	38,000	P					38,000	1
St. George	1942					21,350	NB	21,350	1
St. George	1943					3,450	NB	3,450	1
St. George	1944					30,870	P	30,870	1
St. George	1945					25,180	NB	25,180	1
Tunk Stream	1949	50,000	NB					50,000	1
Tunk Stream	1950	25,000	M+N	9,920	M+N			34,920	1
Tunk Stream	1951			10,000	M+P			10,000	1
Union	1985	6,750	P					6,750	1
Union	1986	6,700	P					6,700	1
Union	1987	6,750	P					6,750	1
Union	1993	60,000	P	111,650				171,650	1
Union	1995			54,800	P			54,800	1
Union	1996			53,500	?			53,500	2
Union	1997	12,000	?	69,300	?			81,300	2
Union	1998	165,000	?					165,000	2
Union	1999	165,000	?	82,100				247,100	2
Union	2001	2,000	?					2,000	2
Union	2002	5,000	?					5,000	2
Union	2003	3,000	?					3,000	2
Upper St. John	1987	306,000	SJ	60,000				366,000	1
Upper St. John	1988	127,600	SJ	779,400		4,750	SJ	911,750	1
Upper St. John	1989	66,000	SJ					66,000	1
Upper St. John	1990	110,000	SJ	21,000		9,900	SJ	140,900	1
Upper St. John	1991	227,500	SJ	139,350				366,850	1
Upper St. John	1992	399,700	SJ	136,100				535,800	1
Upper St. John	1993	360,755	SJ	102,760				463,515	1
Upper St. John	1994	565,700	SJ	216,060				781,760	1

Appendix 4. Summary of sea-run Atlantic salmon smolt stocking for 26 rivers in Maine from 1871 to 2003. Smolt origin code: D = Dennys; EM = East Machias; M = Machias; N = Narraguagus; NB = New Brinswick; ON = Ontario; P = Penobscot; PL = Pleasant; Q = Quebec; SC = St. Croix; SJ = St. John; U = Union; ? = unknown. Note: St. John River has three drainages listed separately - Upper St. John, Aroostook, and Meduxnekeag. Data Source1= Baum (1997), 2= USASAC (1996-2004).

River	Year	1-Year Smolt	1-Yr. Smolt Origin	2-Year Smolt	2-Yr. Smolt Origin	3-Year Smolt	3-Yr. Smolt Origin	Total Smolts	Data Source
Aroostook	1978	5,190	U					5,190	1
Aroostook	1980			2,595	U			2,595	1
Aroostook	1989			10,000	SJ			10,000	1
Aroostook	1990	27,350	SJ	7,570	SJ			34,920	1
Aroostook	1991			9,590	SJ			9,590	1
Boyden	1973			1,000	P			1,000	1
Boyden	1974			500	P			500	1
Boyden	1975			600	P			600	1
Dennys	1942			3,200	D			3,200	1
Dennys	1965	25,570	NB					25,570	1
Dennys	1966	20,000	NB					20,000	1
Dennys	1968	20,510	NB					20,510	1
Dennys	1973			7,020	N			7,020	1
Dennys	1975			4,160	P			4,160	1
Dennys	1976			8,910	P			8,910	1
Dennys	1977	14,820	P					14,820	1
Dennys	1978	15,395	U					15,395	1
Dennys	1979	10,230	P					10,230	1
Dennys	1980			15,220	U			15,220	1

River	Year	1-Year Smolt	1-Yr. Smolt Origin	2-Year Smolt	2-Yr. Smolt Origin	3-Year Smolt	3-Yr. Smolt Origin	Total Smolts	Data Source
Dennys	1983	5,220	U					5,220	1
Dennys	1984	3,290	U					3,290	1
Dennys	1985	4,500	U					4,500	1
Dennys	1986	5,440	P					5,440	1
Dennys	1987	9,040	U					9,040	1
Dennys	1988	11,445	U					11,445	1
Dennys	1988	14,290	P					14,290	1
Dennys	1989	12,130	P					12,130	1
Dennys	1990	25,810	P					25,810	1
Dennys	1991	11,700	P					11,700	1
Dennys	1996			900	D			900	2
Dennys	1998	9,600	D					9,600	2
Dennys	2001	49,800	D					49,800	2
Dennys	2002	49,000	D					49,000	2
Dennys	2003	55,200	D					55,200	2
East Machias	1966	10,480	NB					10,480	1
East Machias	1966			14,405	M			14,405	1
East Machias	1973			2,010	P			2,010	1
East Machias	1975			3,015	P			3,015	1
East Machias	1976			3,915	P			3,915	1
East Machias	1978	3,920	U					3,920	1
East Machias	1978	8,250	P					8,250	1
East Machias	1979	5,150	P					5,150	1

River	Year	1-Year Smolt	1-Yr. Smolt Origin	2-Year Smolt	2-Yr. Smolt Origin	3-Year Smolt	3-Yr. Smolt Origin	Total Smolts	Data Source
East Machias	1980			15,865	U			15,865	1
East Machias	1982			5,600	P			5,600	1
East Machias	1985	4,500	U					4,500	1
East Machias	1986	5,250	U					5,250	1
East Machias	1987	9,000	U					9,000	1
East Machias	1988	20,745	P					20,745	1
East Machias	1989	6,025	U					6,025	1
East Machias	1989	9,275	P					9,275	1
East Machias	1990	10,135	P					10,135	1
East Machias	1991	15,305	P					15,305	1
East Machias	1998	10,800	EM					10,800	2
Kennebunk	1965	2,000	NB					2,000	1
Kennebunk	1966	5,000	NB					5,000	1
Kennebunk	1967	5,000	NB					5,000	1
Kennebunk	1968	4,425	NB					4,425	1
Little Falls (Hobart)	1951			2,010	NB			2,010	1
Machias	1962	35,990	NB					35,990	1
Machias	1963	30,935	NB					30,935	1
Machias	1964	1,585	NB					1,585	1
Machias	1965	38,960	NB					38,960	1
Machias	1966	13,690	N	19,305	N			32,995	1
Machias	1967	14,700	NB					14,700	1
Machias	1967			11,185	M			11,185	1

River	Year	1-Year Smolt	1-Yr. Smolt Origin	2-Year Smolt	2-Yr. Smolt Origin	3-Year Smolt	3-Yr. Smolt Origin	Total Smolts	Data Source
Machias	1968	9,040	N	8,910				17,950	1
Machias	1968	18,390	NB					18,390	1
Machias	1969	11,215	M	25,670	M			36,885	1
Machias	1970			10,670	M			10,670	1
Machias	1971	5,100	M					5,100	1
Machias	1971			3,390	MN			3,390	1
Machias	1972	8,525	P	4,370	PM			12,895	1
Machias	1973			6,120	P			6,120	1
Machias	1974			6,480	N			6,480	1
Machias	1976	5,250	P	11,090	P			16,340	1
Machias	1978	2,665	P					2,665	1
Machias	1978	7,575	U					7,575	1
Machias	1979	4,095	U					4,095	1
Machias	1979	6,105	P					6,105	1
Machias	1980	5,500	P					5,500	1
Machias	1984	15,780	U					15,780	1
Machias	1985	5,130	U					5,130	1
Machias	1987	13,555	U					13,555	1
Machias	1988	14,285	P					14,285	1
Machias	1989	16,615	U					16,615	1
Machias	1990	23,115	P					23,115	1
Machias	1991	26,090	P					26,090	1
Machias	1992	21,080	P					21,080	1

River	Year	1-Year Smolt	1-Yr. Smolt Origin	2-Year Smolt	2-Yr. Smolt Origin	3-Year Smolt	3-Yr. Smolt Origin	Total Smolts	Data Source
Machias	1996			1,900	M			1,900	2
Machias	1998	10,800	M					10,800	2
Meduxnekeag	1980	2,730	U					2,730	1
Narraguagus	1962	35,620	NB					35,620	1
Narraguagus	1963	34,660	NB					34,660	1
Narraguagus	1964	18,105	NB					18,105	1
Narraguagus	1965	34,185	NB					34,185	1
Narraguagus	1966	24,460	N	24,850	N			49,310	1
Narraguagus	1967	15,830	NB					15,830	1
Narraguagus	1967			19,110	MN			19,110	1
Narraguagus	1968			4,945	N			4,945	1
Narraguagus	1968	11,760	NB					11,760	1
Narraguagus	1968			6,855	MN			6,855	1
Narraguagus	1969	9,875	N	15,925	N			25,800	1
Narraguagus	1970			1,925	MN			1,925	1
Narraguagus	1970			9,895	N			9,895	1
Narraguagus	1971			2,875	MN			2,875	1
Narraguagus	1972			15,700	PM			15,700	1
Narraguagus	1973			5,560	P			5,560	1
Narraguagus	1975			5,000	P			5,000	1
Narraguagus	1976			8,430	P			8,430	1
Narraguagus	1979	4,555	P					4,555	1
Narraguagus	1979	5,575	U					5,575	1

River	Year	1-Year Smolt	1-Yr. Smolt Origin	2-Year Smolt	2-Yr. Smolt Origin	3-Year Smolt	3-Yr. Smolt Origin	Total Smolts	Data Source
Narraguagus	1980			20,430	U			20,430	1
Narraguagus	1981			4,080	U			4,080	1
Narraguagus	1982			5,200	P			5,200	1
Narraguagus	1984	5,200	U					5,200	1
Narraguagus	1985	4,500	U					4,500	1
Narraguagus	1986	7,510	U					7,510	1
Narraguagus	1987	9,020	U					9,020	1
Narraguagus	1988	5,215	U					5,215	1
Narraguagus	1988	10,455	P					10,455	1
Narraguagus	1989	22,110	P	4,900	P			27,010	1
Narraguagus	1990	16,750	P					16,750	1
Narraguagus	1991	15,225	P					15,225	1
Narraguagus	1997	700	N					700	2
Narraguagus	1999	1,000	N					1,000	2
Orland	1963	36,055	NB					36,055	1
Orland	1964	5,515	Q					5,515	1
Orland	1965	49,370	NB					49,370	1
Orland	1966	40,000	NB					40,000	1
Orland	1967	19,890	NB					19,890	1
Orland	1968	18,525	OP					18,525	1
Orland	1969	6,790	OP					6,790	1
Penobscot	1945		P	16,295	P			16,295	1
Penobscot	1946		P	13,980	P			13,980	1

River	Year	1-Year Smolt	1-Yr. Smolt Origin	2-Year Smolt	2-Yr. Smolt Origin	3-Year Smolt	3-Yr. Smolt Origin	Total Smolts	Data Source
Penobscot	1947		P	5,640	P			5,640	1
Penobscot	1962	34,030	NB					34,030	1
Penobscot	1965	29,705	NB					29,705	1
Penobscot	1966			7,005	N			7,005	1
Penobscot	1967	38,090	NB					38,090	1
Penobscot	1967			5,690	M			5,690	1
Penobscot	1968			7,085	N			7,085	1
Penobscot	1968			12,690	MN			12,690	1
Penobscot	1968			28,925	M			28,925	1
Penobscot	1969	900	MN	8,545	M			9,445	1
Penobscot	1969			18,375	MN			18,375	1
Penobscot	1970					1,080	MN	1,080	1
Penobscot	1970			1,555	N			1,555	1
Penobscot	1970			2,585	MN			2,585	1
Penobscot	1970			23,280	M			23,280	1
Penobscot	1971	18,675	P					18,675	1
Penobscot	1971	33,915	M					33,915	1
Penobscot	1972			3,515	PM			3,515	1
Penobscot	1972			10,480	P			10,480	1
Penobscot	1972			14,470	M			14,470	1
Penobscot	1972			45,330	N			45,330	1
Penobscot	1973	4,235	N	44,285	MN			48,520	1
Penobscot	1973	8,170	P	51,600	P			59,770	1

River	Year	1-Year Smolt	1-Yr. Smolt Origin	2-Year Smolt	2-Yr. Smolt Origin	3-Year Smolt	3-Yr. Smolt Origin	Total Smolts	Data Source
Penobscot	1974			48,340	P			48,340	1
Penobscot	1974	34,320	P					34,320	1
Penobscot	1974			17,510	PN			17,510	1
Penobscot	1975	15,760	P	94,800	P			110,560	1
Penobscot	1976	54,655	P	180,030	P			234,685	1
Penobscot	1977					325	P	325	1
Penobscot	1977	113,760	P	224,355	P			338,115	1
Penobscot	1978	38,560	U	29,035	U			67,595	1
Penobscot	1978	22,560	P	112,325	P			134,885	1
Penobscot	1979	11,580	U	123,585	U			135,165	1
Penobscot	1979	38,465	P	112,670	P			151,135	1
Penobscot	1980	84,710	U	51,980	U			136,690	1
Penobscot	1980	284,305	P	163,805	P			448,110	1
Penobscot	1981	1,595	U	285	U			1,880	1
Penobscot	1981	23,095	P	174,510	P			197,605	1
Penobscot	1982	107,370	P	222,325	P			329,695	1
Penobscot	1983	164,800	U					164,800	1
Penobscot	1983	116,745	P	161,415	P			278,160	1
Penobscot	1984	7,775	U					7,775	1
Penobscot	1984	473,750	P	135,595	P			609,345	1
Penobscot	1985	3,400	PU					3,400	1
Penobscot	1985	54,325	U					54,325	1
Penobscot	1985	418,760	P	104,435	P			523,195	1

River	Year	1-Year Smolt	1-Yr. Smolt Origin	2-Year Smolt	2-Yr. Smolt Origin	3-Year Smolt	3-Yr. Smolt Origin	Total Smolts	Data Source
Penobscot	1986	1,435	U					1,435	1
Penobscot	1986	518,780	P	68,990	P			587,770	1
Penobscot	1987	10,920	U					10,920	1
Penobscot	1987	445,850	P	82,420	P			528,270	1
Penobscot	1988	38,070	U					38,070	1
Penobscot	1988	561,830	P	87,055	P			648,885	1
Penobscot	1989	21,950	U					21,950	1
Penobscot	1989	329,345	P	65,325	P			394,670	1
Penobscot	1990	20,630	U					20,630	1
Penobscot	1990	392,545	P	15,895	P			408,440	1
Penobscot	1991	657,785	P	15,015	P			672,800	1
Penobscot	1992	816,565	P	8,075	P			824,640	1
Penobscot	1993	580,435	P					580,435	1
Penobscot	1994	567,605	P					567,605	2
Penobscot	1995	568,400	P					568,400	1
Penobscot	1996	552,200	P					552,200	2
Penobscot	1997	580,200	P					580,200	2
Penobscot	1998	571,800	P					571,800	2
Penobscot	1999	567,300	P					567,300	2
Penobscot	2000	563,200	P					563,200	2
Penobscot	2001	454,000	P					454,000	2
Penobscot	2002	547,000	P					547,000	2
Penobscot	2003	547,300	P					547,300	2

River	Year	1-Year Smolt	1-Yr. Smolt Origin	2-Year Smolt	2-Yr. Smolt Origin	3-Year Smolt	3-Yr. Smolt Origin	Total Smolts	Data Source
Pleasant	1966	10,000	NB					10,000	1
Pleasant	1968	13,550	NB					13,550	1
Pleasant	1975			3,000	P			3,000	1
Pleasant	1976			1,020	P			1,020	1
Pleasant	1978	3,100	U					3,100	1
Pleasant	1980	245	P	9,980	U			10,225	1
Pleasant	1981			4,080	U			4,080	1
Pleasant	1982	5,000	P					5,000	1
Pleasant	1985	4,110	U					4,110	1
Pleasant	1986	6,530	U					6,530	1
Pleasant	1987	7,475	U					7,475	1
Pleasant	1988	10,460	P					10,460	1
Pleasant	1989	7,300	P					7,300	1
Pleasant	1990	10,505	P					10,505	1
Pleasant	2003	2,800	PL					2,800	2
Saco	1975			9,475	P			9,475	1
Saco	1983	20,340	U					20,340	1
Saco	1984	5,130	P					5,130	1
Saco	1985	5,100	P					5,100	1
Saco	1986	35,170	P					35,170	1
Saco	1987	22,015	P					22,015	1
Saco	1988	25,140	P					25,140	1
Saco	1989	9,890	P					9,890	1

River	Year	1-Year Smolt	1-Yr. Smolt Origin	2-Year Smolt	2-Yr. Smolt Origin	3-Year Smolt	3-Yr. Smolt Origin	Total Smolts	Data Source
Saco	1990	10,625	P					10,625	1
Saco	1991	10,320	P					10,320	1
Saco	1992	19,850	P					19,850	1
Saco	1993	20,055	P					20,055	1
Saco	1994	2,000	P					2,000	1
Saco	1995	19,700	P					19,700	1
Saco	1996	20,000	P					20,000	2
Saco	1997	20,200	P					20,200	2
Saco	1998	21,300	P					21,300	2
Saco	1999	20,100	P					20,100	2
Saco	2000	22,600	P					22,600	2
Saco	2001	400	P					400	2
Saco	2002	4,100	P					4,100	2
Saco	2003	3,200	P					3,200	2
Sheepscot	1965	14,210	NB					14,210	1
Sheepscot	1966	25,040	NB					25,040	1
Sheepscot	1967	10,515	NB					10,515	1
Sheepscot	1968	15,980	NB					15,980	1
Sheepscot	1971	1,020	M					1,020	1
Sheepscot	1973			1,025	P			1,025	1
Sheepscot	1975			2,520	P			2,520	1
Sheepscot	1976	3,000	P					3,000	1
Sheepscot	1982	5,310	P					5,310	1

River	Year	1-Year Smolt	1-Yr. Smolt Origin	2-Year Smolt	2-Yr. Smolt Origin	3-Year Smolt	3-Yr. Smolt Origin	Total Smolts	Data Source
Sheepscot	1983	5,175	P					5,175	1
Sheepscot	1984	5,005	P					5,005	1
Sheepscot	1985	3,860	P	3,645	P			7,505	1
Sheepscot	1986	7,510	P					7,510	1
Sheepscot	1987	9,000	P					9,000	1
Sheepscot	1988	10,245	P					10,245	1
Sheepscot	1989	10,235	P					10,235	1
Sheepscot	1990	16,500	P					16,500	1
Sheepscot	1991	14,375	P					14,375	1
St. Croix	1965	51,610	NB					51,610	1
St. Croix	1965			50,170	M			50,170	1
St. Croix	1966	55,380	NB					55,380	1
St. Croix	1967	12,015	NB					12,015	1
St. Croix	1969	13,590	M					13,590	1
St. Croix	1981			13,670	P			13,670	1
St. Croix	1982			80	P			80	1
St. Croix	1982	19,900	P	6,295	U			26,195	1
St. Croix	1983	20,040	U					20,040	1
St. Croix	1984	11,860	P					11,860	1
St. Croix	1984	80,665	U					80,665	1
St. Croix	1985	29,790	P					29,790	1
St. Croix	1985	29,800	U					29,800	1
St. Croix	1986	4,470	U					4,470	1

River	Year	1-Year Smolt	1-Yr. Smolt Origin	2-Year Smolt	2-Yr. Smolt Origin	3-Year Smolt	3-Yr. Smolt Origin	Total Smolts	Data Source
St. Croix	1986	68,990	P					68,990	1
St. Croix	1987	28,455	P					28,455	1
St. Croix	1987	31,300	U					31,300	1
St. Croix	1988	78,745	P					78,745	1
St. Croix	1989	50,575	P					50,575	1
St. Croix	1990	65,765	P					65,765	1
St. Croix	1991	60,220	P					60,220	1
St. Croix	1992	50,340	P					50,340	1
St. Croix	1993	40,110	P					40,110	1
St. Croix	1994	60,600	SC					60,600	2
St. Croix	1996	15,600	P					15,600	2
St. Croix	1999	21,300	P					21,300	2
St. Croix	2000	2,000	P					2,000	2
St. Croix	2001	8,100	P					8,100	2
St. Croix	2002	4,100	P					4,100	2
St. Croix	2003	3,200	P					3,200	2
St. George	1943			6,730	NB			6,730	1
Union	1971	8,120	M					8,120	1
Union	1972			7,710	M			7,710	1
Union	1973			19,550	P			19,550	1
Union	1974			8,645	P			8,645	1
Union	1974	9,925	P	11,800	N			21,725	1
Union	1975			31,250	P			31,250	1

River	Year	1-Year Smolt	1-Yr. Smolt Origin	2-Year Smolt	2-Yr. Smolt Origin	3-Year Smolt	3-Yr. Smolt Origin	Total Smolts	Data Source
Union	1976	1,805	U					1,805	1
Union	1976			31,760	P			31,760	1
Union	1977	13,025	U					13,025	1
Union	1977			22,465	P			22,465	1
Union	1978			31,940	U			31,940	1
Union	1979			14,970	U			14,970	1
Union	1979	12,935	U					12,935	1
Union	1979			14,955	P			14,955	1
Union	1980	30,640	U					30,640	1
Union	1981			29,385	U			29,385	1
Union	1981			5,860	P			5,860	1
Union	1982	5,860	U					5,860	1
Union	1982			20,675	U			20,675	1
Union	1983	41,605	U					41,605	1
Union	1984	1,870	P					1,870	1
Union	1984	48,365	U					48,365	1
Union	1985	45,755	U					45,755	1
Union	1986	48,360	U					48,360	1
Union	1987	7,825	PU					7,825	1
Union	1987	32,295	U					32,295	1
Union	1988	15,250	U					15,250	1
Union	1988	15,345	P					15,345	1
Union	1989	20,360	?					20,360	1

River	Year	1-Year Smolt	1-Yr. Smolt Origin	2-Year Smolt	2-Yr. Smolt Origin	3-Year Smolt	3-Yr. Smolt Origin	Total Smolts	Data Source
Union	1990	10,150	P					10,150	1
Union	1990	10,210	U					10,210	1
Upper St. John	1988			10,260	SJ			10,260	1
Upper St. John	1989			10,260	SJ			10,260	1
Upper St. John	1990			5,110	SJ			5,110	1
Upper St. John	1991	5,070	SJ					5,070	1

Appendix 5. Summary of sea-run Atlantic salmon adult stocking in Maine from 1871 to 1995. Adult origin code: P = Penobscot; SJ = St. John; U = Union; ? = unknown. Note: St. John River has two drainages listed separately- Upper St. John, and Aroostook. Data from Baum (1997). Domestic broodstock are from Green Lake National Fish Hatchery

River	Year Stocked	Origin	1 Sea-Winter	Multiple Sea-Winter	Total Stocked
Aroostook	1980	P		12	12
Aroostook	1981	P		18	18
Aroostook	1981	U		7	7
Aroostook	1983	SJ	34		34
Aroostook	1984	SJ	58	29	87
Aroostook	1985	SJ	65	24	89
Aroostook	1986	SJ	50		50
Aroostook	1987	SJ	77	9	86
Aroostook	1988	SJ	70	30	100
Aroostook	1989	SJ	86	35	121
Aroostook	1991	SJ	50	50	100
Aroostook	1992	SJ	225	90	315
Aroostook	1993	SJ	85	71	156
Aroostook	1994	SJ	105	16	121
Aroostook	1995	SJ	100	40	140
Kennebec	1989	P,U	Domestic		447
Kennebec	1990	P,U	Domestic		338
Kennebec	1991	P,U	Domestic		114
Kennebec	1992	P,U	Domestic		515
Kennebec	1993	P,U	Domestic		753
St. Croix	1980	SJ	118	326	444
Union	1982	P,U	Domestic		484
Union	1983	P,U	Domestic		474
Union	1984	P,U	Domestic		229
Union	1985	P,U	Domestic		229
Union	1986	P,U	Domestic		875
Union	1993	P,U	Domestic		754
Upper St. John	1986	SJ		12	12
Upper St. John	1991	SJ	90	50	140
Upper St. John	1992	SJ	230	110	340
Upper St. John	1993	SJ	109	64	173
Upper St. John	1994	SJ	62	17	79

Appendix 6. Total numbers and origin of Atlantic salmon fry and parr stocked in Maine rivers from 1871 to 2003.

River	Total Fry/Parr Stocked (1871-2003)	% Unknown Origin Stocked	% Within Basin Origin Stocked	% Other Maine Origin Stocked	% Out of Maine Origin Stocked	Total Years of Stocking
Androscoggin	300,700			100%		6
Boyden	20,300			100%		1
Dennys	5,250,225		27%	29%	44%	55
Ducktrap	82,690			100%		6
East Machias	1,842,600		88%	12%		18
Kennebec	139,460			100%		4
Kennebunk	10,000			100%		1
Little Falls (Hobart)	80,250			44%	56%	8
Machias	3,508,615	1%	71%	20%	7%	42
Medomak	43,000			100%		2
Narraguagus	4,466,155		53%	21%	26%	43
Orland	250,980		3%	92%	5%	8
Pennamaquan	428,610			100%		3
Penobscot	70,802,820		87%	1%	12%	100
Pleasant	816,410		12%	79%	9%	18
Presumscot	132,000			100%		2
Saco	5,108,530			100%		21
Sheepscot	2,303,765		70%	17%	13%	30
Somesville	29,900			49%	51%	4
St. Croix	2,870,140	23%		57%	20%	35
St. George	118,850			58%	42%	5
St. John	7,026,400	11%	68%	6%	15%	47
Tunk Stream	94,920			47%	53%	3
Union	803,550	69%		31%		12
Total	106,630,870					

Appendix 7. Total numbers and origin of Atlantic salmon smolts stocked in Maine rivers from 1871 to 2003.

River	Total Smolts Stocked (1871-2003)	% Unknown Origin Stocked	% Within Basin Origin Stocked	% Other Maine Origin Stocked	% Out of Maine Origin Stocked	Total Years of Stocking
Boyden	2,100			100%		3
Dennys	412,400		41%	43%	16%	25
East Machias	163,645		7%	87%	6%	26
Kennebunk	16,425				100%	4
Little Falls (Hobart)	2,010				100%	1
Machias	474,860		16%	54%	30%	27
Narraguagus	447,990		20%	46%	34%	28
Orland	176,145			14%	86%	7
Penobscot	14,775,665		93%	6%	1%	43
Pleasant	99,155		3%	73%	24%	15
Saco	326,710			100%		22
Sheepscot	164,170			60%	40%	18
St. Croix	988,735		6%	82%	12%	24
St. George	6,730				100%	1
St. John	95,725		89%	11%		26
Union	630,665	3%	64%	33%		20
Total	18,783,130					

Appendix 8. Matrix of listing factors and stressors affecting the GOM DPS at each life stage. The magnitude of each stressor was categorized according to the geographic extent and stressor severity was categorized according to severity for each life stage.

			STRESSOR SEVERITY AT EACH LIFE STAGE 1 = high, possible synergistic effects 2 = moderate 3 = low 4 = negligible to no threat 5 = potentially significant 6 = uncertain						
Listing Factor	**Stressor**	Magnitude **1=all large rivers, 2=some large rivers, 3=no large rivers, 4= all small rivers, 5=some small rivers, 6=no small rivers**	early freshwater	fry	parr	smolt	near shore marine	offshore marine	adult
Present or Threatened Destruction, Modification, or Curtailment of Habitat or Range									
	Surface and groundwater withdrawals for agricultural irrigation and increased municipal use	2,5	3	2	2	3	3	4	1
	Acidified water/aluminum toxicity	2,5	2	3	3	1	4	4	3
	Point source contaminant (e.g., industrial spills, transportation related spills, organics)	1,5	2	2	3	2	4	4	3

			STRESSOR SEVERITY AT EACH LIFE STAGE 1 = high, possible synergistic effects 2 = moderate 3 = low 4 = negligible to no threat 5 = potentially significant 6 = uncertain						
Listing Factor	**Stressor**	Magnitude **1=all large rivers, 2=some large rivers, 3=no large rivers, 4= all small rivers, 5=some small rivers, 6=no small rivers**	early freshwater	fry	parr	smolt	near shore marine	offshore marine	adult
	Non-point source (e.g., endocrine disruptors, pesticides, fine sediment, organics)	1,4	2	2	3	2	4	4	3
	Altered habitat through altered thermal regimes	1,4	2	2	2	2	5	5	2
	Structurally simplified river channels resulting in altered habitat forming processes	1,4	4	3	1	3	4	4	3
	Altered habitat through altered hydrological regimes	1,5	2	3	2	2	4	4	2
	Dams - range curtailment	1,5	4	4	4	4	4	4	1
	Dams - inundating rearing and spawning habitat	1,5	3	2	2	4	4	4	2

STRESSOR SEVERITY AT EACH LIFE STAGE

1 = high, possible synergistic effects
2 = moderate
3 = low
4 = negligible to no threat
5 = potentially significant
6 = uncertain

Listing Factor	**Stressor**	Magnitude **1=all large rivers, 2=some large rivers, 3=no large rivers, 4= all small rivers, 5=some small rivers, 6=no small rivers**	early freshwater	fry	parr	smolt	near shore marine	offshore marine	adult
	Dams - altered behavioral and physiological cues	1,5	4	4	4	2	4	4	2
	Dams - salmon passage ineffficiency	1,5	4	4	3	1	4	4	1
	Dams - altering physical and chemical habitat to favor invasive spp.	1,5	3	2	1	2	4	4	3
	Dams - altering riverine fish communities	1,5	3	5	5	1	1	4	5
	Dams - alter native resident aquatic communities	1,5	3	3	3	3	4	4	3
	Roads and culverts diminishing passage	1,4	4	3	2	2	4	4	3

			STRESSOR SEVERITY AT EACH LIFE STAGE 1 = high, possible synergistic effects 2 = moderate 3 = low 4 = negligible to no threat 5 = potentially significant 6 = uncertain						
Listing Factor	**Stressor**	Magnitude **1=all large rivers, 2=some large rivers, 3=no large rivers, 4= all small rivers, 5=some small rivers, 6=no small rivers**	early freshwater	fry	parr	smolt	near shore marine	offshore marine	adult
	Beaver dams diminshing passage and inundating habitat	2,5	4	4	3	3	4	4	3
Overutilization for Commercial, Recreational, Scientific, or Educational Purposes									
	Incidental capture and release by recreational anglers (freshwater and marine)	1,4	4	4	3	3	4	4	1
	Targeted poaching	2,5	4	4	3	4	4	4	1
	Commercial bycatch	1,4	4	4	3	3	3	3	3

			STRESSOR SEVERITY AT EACH LIFE STAGE 1 = high, possible synergistic effects 2 = moderate 3 = low 4 = negligible to no threat 5 = potentially significant 6 = uncertain						
Listing Factor	**Stressor**	Magnitude **1=all large rivers, 2=some large rivers, 3=no large rivers, 4= all small rivers, 5=some small rivers, 6=no small rivers**	early freshwater	fry	parr	smolt	near shore marine	offshore marine	adult
	Scientific sampling and assessment	1,5	4	4	3	3	3	4	3
Predation, Disease, and Competition									
	Predation by marine mammals	1,4	4	4	4	3	3	5	5
	Predation by other mammals	1,4	4	4	3	3	3	4	4
	Predation by birds	1,4	4	4	3	2	3	3	4
	Predation and competition by non-native freshwater fish	1,4	4	2	1	2	4	4	4

		Magnitude	STRESSOR SEVERITY AT EACH LIFE STAGE 1 = high, possible synergistic effects 2 = moderate 3 = low 4 = negligible to no threat 5 = potentially significant 6 = uncertain						
Listing Factor	**Stressor**	**1=all large rivers, 2=some large rivers, 3=no large rivers, 4= all small rivers, 5=some small rivers, 6=no small rivers**	early freshwater	fry	parr	smolt	near shore marine	offshore marine	adult
	Predation and competition by native freshwater fish	1,4	4	4	4	4	4	4	4
	Predation and competition by estuarine and marine fish	1,4	4	4	4	4	3	3	3
	Competion among hatchery, naturally reared, and wild juveniles	2,5	4	2	2	3	4	4	4
	Competition and predation by excess broodstock with wild and restoration stocks	3,5	4	4	3	3	4	4	4
	Diseases not endemic to the GOM DPS	1, 4	6	6	6	6	6	6	6
	Furunculosis	1, 4	4	4	3	3	3	3	3
	ISA	3, 5	4	4	4	3	3	6	3

		Magnitude	STRESSOR SEVERITY AT EACH LIFE STAGE 1 = high, possible synergistic effects 2 = moderate 3 = low 4 = negligible to no threat 5 = potentially significant 6 = uncertain						
Listing Factor	**Stressor**	**1=all large rivers, 2=some large rivers, 3=no large rivers, 4= all small rivers, 5=some small rivers, 6=no small rivers**	early freshwater	fry	parr	smolt	near shore marine	offshore marine	adult
	SSSV	3, 4	6	6	6	6	6	6	3
	BKD	2, 5	4	4	4	3	3	3	3
	Cold water disease	2, 5	3	3	6	6	6	6	6
Inadequacy of Existing Regulatory Mechanisms									

		Magnitude	STRESSOR SEVERITY AT EACH LIFE STAGE 1 = high, possible synergistic effects 2 = moderate 3 = low 4 = negligible to no threat 5 = potentially significant 6 = uncertain						
Listing Factor	**Stressor**	**1=all large rivers, 2=some large rivers, 3=no large rivers, 4= all small rivers, 5=some small rivers, 6=no small rivers**	early freshwater	fry	parr	smolt	near shore marine	offshore marine	adult
Other Natural or Manmade Factors Affecting Its Continued Existence									
	Unfavorable ocean conditions	1,4	4	4	4	4	2	1	4
	Elevated pathogen and parasite transmission aquaculture	1,4	3	3	3	3	2	4	2
	Competion among aquaculture escapees, naturally reared, and wild salmon	2,5	3	3	3	4	4	4	3
	Genetic introgression from aquaculture escapees	1,4	2	2	2	2	2	2	2
	Artificial selection and domestication	2,5	1	1	1	1	1	1	1

			STRESSOR SEVERITY AT EACH LIFE STAGE 1 = high, possible synergistic effects 2 = moderate 3 = low 4 = negligible to no threat 5 = potentially significant 6 = uncertain						
Listing Factor	**Stressor**	Magnitude **1=all large rivers, 2=some large rivers, 3=no large rivers, 4= all small rivers, 5=some small rivers, 6=no small rivers**	early freshwater	fry	parr	smolt	near shore marine	offshore marine	adult
	Effective population size	1,4	1	1	1	1	1	1	1
	Maintenance of all stocks at a few sites	2,5	1	1	1	1	1	1	1
	Lack of hatchery stock	2,5	1	1	1	1	1	1	1
	Over representation of genetic contribution from excess broodstock	3,5	4	4	4	4	4	4	4
	NGO rearing - salmon in schools	2,6	4	4	4	4	4	4	4
	Climate Change	1,4	5	5	5	5	5	5	5
	Management of hatchery products	2,5	4	3	3	2	4	4	4
	Land use change (e.g., forestry, EMF)	1,4	2	3	2	2	3	4	2

			STRESSOR SEVERITY AT EACH LIFE STAGE 1 = high, possible synergistic effects 2 = moderate 3 = low 4 = negligible to no threat 5 = potentially significant 6 = uncertain						
		Magnitude							
Listing Factor	**Stressor**	**1=all large rivers, 2=some large rivers, 3=no large rivers, 4= all small rivers, 5=some small rivers, 6=no small rivers**	early freshwater	fry	parr	smolt	near shore marine	offshore marine	adult
	Freshwater productivity	1,4	2	2	1	1	4	4	2

Appendix 9. Waters impaired by pollutants and hydroelectric operations within the range of the GOM DPS (data from MDEP 2004).

Watershed	Segment Name	Segment Size	Segment Class	Impaired Use	Causes and Potential Sources
All Fresh, Estuarine, and Marine waters of the State of Maine		N/A	N/A	Partially, Fishing (Consumption)	Atmospheric Deposition of Mercury
West branch Penobscot River	West Branch of Penobscot River below Seboomook Lake	1.0 mile	Class A,B	Aquatic Life	Flow modified for hydropower. New hydro certification pending.
	West Branch Penobscot River, main stem, below outlet of Quakish Lake	4.2 miles	Class C	Aquatic Life Navigation	Flow diversion - modified for hydropower.
	Millinocket Stream (Millinoket)	3.2 miles	Class C	Recreation	Bacteria-Non-Point Source (Unspecified)
	Canada Falls Lake	2,627 acres	NA	Aquatic Life	Lake draw down
	Seboomook Lake	6,448 acres	NA	Aquatic Life	Lake draw down
	Caucomgomoc Lake	5,081 acres	NA	Aquatic Life	Lake draw down
	Ragged Lake	2,712 acres	NA	Aquatic Life	Lake draw down
Piscataquis River	Sebec River at Milo above confluence with Piscatiquis River	1.5 miles	Class B	Aquatic Life	General Development Non-Point Sources; Bacteria-Combined Sewer Overflows, Milo
	Piscatiquis River main stem, below Dover Foxcroft	12.0 miles	Class B	Aquatic Life	Low Dissolved Oxygen - Agricultural Non-Point Sources, Municipal Point sources. Bacteria-Combined Sewer Overflows Dover Foxcroft
	West Branch Pleasant River (Katahdin Iron Works Township)	1.0 miles	Class AA,A	Aquatic Life	Non-Point Source – Abandoned mine (circa 1800s)
	Blood Bk (Katahdin Iron Works Township)	1.0 miles	Class A	Aquatic Life	Non-Point Source – Abandoned mine (circa 1800s)

Watershed	Segment Name	Segment Size	Segment Class	Impaired Use	Causes and Potential Sources
Penobscot River	Penobscot River, main stem, from Piscataquis River to Reed Brook	61.1 miles	Class B	Fishing (Consumption)	Industrial Point Sources (Dioxin), Bacteria; Combined Sewer Overflows, Milford, Old Town, Orono, Bangor, Brewer
	Silver Lake Outlet	1.3 miles	Class B	Aquatic Life	Water withdrawal
	Mattanawcook Stream (Lincoln)	1.2 miles	Class C	Aquatic Life Recreation	Low Dissolved Oxygen and Bacteria Industrial and Urban Non-Point Sources
	Penobscot River main stem, from Mattawamkeag River to Cambolassee Stream	16.0	Class C	Aquatic Life	Low Dissolved Oxygen, Nutrients, and Aquatic Life Criteria. Industrial and Urban Point Sources
	Penobscot River, main stem, from Cambolasse Str to Piscataquis River	20.5	Class B,C	Aquatic life Fishing (Consumption)	Aquatic life criteria, Dissolved oxygen Nutrients, and Dioxin; Industrial and Municipal Point Sources,
	Cold Stream (Enfield) downstream of hatchery	1.0	Class A	Aquatic Life	Aquatic life criteria, Aquaculture Point Source
	Costigan Stream (Costigan)	1.2	Class B	Aquatic Life Recreation	Dissolved oxygen and Bacteria, Unknown (untreated waste?)
	Penjajawoc Stream (Bangor), Meadow Brook (Bangor)	6.3	Class B	Aquatic life Meadow Brook -Threatened)	Aquatic life criteria and Dissolved oxygen Urban Non-Point Sources and Habitat Degradation
	Burnham Brook (Garland)	3.7	Class B	Aquatic Life	Dissolved oxygen Non-Point Source (unspecified)

Watershed	Segment Name	Segment Size	Segment Class	Impaired Use	Causes and Potential Sources
Penobscot River	French Stream (Exeter)	10.2	Class B	Aquatic Life	Aquatic life criteria, Agricultural Non-Point Source
	Birch Stream (Bangor)	0.5	Class B	Aquatic Life	Aquatic life criteria, Urban Non-Point Source (Airport runoff, de-icing)
	Unnamed (Pushaw) Stream (Bangor)	0.5	Class B	Aquatic Life	Aquatic life criteria, Urban Non-Point Source
	Arctic Brook (near Valley Avenue Bangor)	0.5	Class B	Aquatic Life	Aquatic life criteria, Urban Non-Point Source
	Shaw Brook (Bangor, Hampden)	5.5	Class B	Aquatic Life	Aquatic life criteria, Urban Non-Point Source
	Unnamed Stream (Hampden) 44.77326/68.79467	1.0	Class B	Aquatic Life	Aquatic life criteria, General Development Non-Point Source
	Otter Stream	6.3 miles	Class B	Recreation	Bacteria, Unknown Untreated waste? Non-Point Source (unspecified)
	Boynton Brook	2.6 miles	Class B	Recreation	Bacteria, Unknown Untreatedwaste? Non-Point Source (unspecified)
	Kenduskeag Stream	1.5 miles	Class B,C	Recreation	BacteriaUnknown Untreated waste? Non-Point Source (unspecified)
	Hammond Pond	83 acres	NA	Recreation (Primary Contact)	Needs Total Maximum Daily Load Report
	Hermon Pond	461 acres	NA	Recreation (Primary Contact)	Needs Total Maximum Daily Load Report

Watershed	Segment Name	Segment Size	Segment Class	Impaired Use	Causes and Potential Sources
Penobscot River	Upper Penobscot River Estuary	7808 acres	SC	Fish Consumption	Mercury, Dioxin, PCBs, and Bacteria; Industrial Point Sources, and Combined Sewer Overflows
	Lower Penobscot River Estuary	12,743.0 acres	SB/SC	Recreation (Primary Contact)	Bacteria; Sewage Treatment Plant, Overboard Discharges, Boats, Elevated fecals, Nonpoint Source
Kennebec River	Brassua Lake	8979 acres	NA	Aquatic Life	Lake draw down
Dead River	Dead River, main stem	1.0 mile	Class AA,A	Aquatic Life	Flow modified for hydropower. New hydro certification pending.
	Flagstaff Lake	20300 acres	NA	Aquatic Life	Lake draw down
Kennebec River	Cobbossee Stream (Gardiner)	1.5 miles	Class B	Aquatic Life	Point and Non-Point sources (Phosphorus)
	Kennebec River, main stem,from Carrabassett River to Fairfield-Skowhegan boundary	22.8 miles	Class B	Fishing (Consumption)	Industrial Point Sources (Dioxin), Bacteria-Combined Sewer Overflows, Skowhegan
	Kennebec River, main stem, from Fairfield-Skowhegan boundary to Sebasticook River	14.7 miles	Class C	Aquatic Life Fishing (Consumption)	Industrial Point Sources (Dioxin), Bacteria-Combined Sewer Overflows, Fairfield, Impoundments
	East Branch Sebasticook River Corundel Pd to Sebasticook Lake	4.5 miles	Class C	Fishing (Consumption)	Hazardous Waste Remediation Project (Superfund)
	Kennebec River, main stem,from Sebasticook R to Augusta (Curran Bridge)	17.7 miles	Class B	Fishing (Consumption)	Industrial Point Sources (Dioxin), Bacteria-Combined Sewer Overflows, at Augusta

Watershed	Segment Name	Segment Size	Segment Class	Impaired Use	Causes and Potential Sources
Kennebec River	Kennebec River, main stem, from Augusta (Curran Bridge) to Merrymeeting Bay (Chops)	30.5 miles	Class C	Fishing (Consumption)	Industrial Point Sources (Dioxin), Bacteria-Combined Sewer Overflows, Gardiner, Randolph and Hallowell
	Merrymeeting Bay, including tidal portions of tributaries from the Androscoggin River to The Chops	3.4 miles	Class B	Fishing(Consumption)	Industrial Point Sources (Dioxin)
	Sebasticcok River, main stem, from East and West Branches to Burnham (bridge)	8.6 miles	Class C	Aquatic Life	Impounded water. New hydro certification pending.
	Sebasticook River (Halifax impoundment)	2.0 miles	Class C	Aquatic Life	Impounded water. Dam removal decision pending.
	Mill Stream (Embden)	2.0 miles	Class B	Aquatic Life	Aquatic life criteria, Aquaculture Point Source
	Sandy River, main stem, segment below Farmington Waste Water Treatment Plant	3.0 miles	Class B	Aquatic Life	Aquatic life criteria, Municipal Point Source
	Unnamed tributary to Sandy River 44.79788/70.31753	0.5 miles	Class B	Aquatic Life	Aquatic life criteria, Aquaculture Point Source
	Cold Stream (Skowhegan)	5.4 miles	Class B	Aquatic Life	Aquatic life criteria, General Development Non-Point Source
	Mill Stream (Norridgewock)	6.5 miles	Class B	Aquatic Life	Aquatic life criteria, Waste Disposal and Habitat Degradation

Watershed	Segment Name	Segment Size	Segment Class	Impaired Use	Causes and Potential Sources
Kennebec River	Whitten Brook (Skowhegan)	1.0 miles	Class B	Aquatic Life Recreation	Bacteria, Aquatic life criteria, Urban Non-Point Source
	West Branch of Sebasticook River, main stem, below Rt. 23 bridge in Hartland	14.8 miles	Class C	Fishing (Consumption)	Dioxin, PCBs (toxic sources removed - Superfund), Municipal and Industrial Point Sources
	East Branch of Sebasticook River, main stem, below Sebasticook Lake	9.0 miles	Class C	Aquatic Life Fishing (Consumption)	Dissolved Oxygen, Dioxin, PCBs (toxic sources removed - Superfund). Eutrophic lake source, Agricultural Non-Point Source, Non-Point Source, (unspecified)
	Brackett Brook (Palmyra)	2.0 miles	Class B	Aquatic Life	Dissolved Oxygen, Non-Point Source, (unspecified)
	Mulligan Stream (St. Albans)	3.7 miles	Class B	Aquatic Life	Dissolved Oxygen, Non-Point Source, (unspecified)
	Sebasticook River, main stem,below confluence of East and West Branches	18.0 miles	Class C	Aquatic Life	Dissolved oxygen, Nutrients, Dioxin,PCBs Municipal and Industrial Point Sources, Impounded Water
	Mill Stream (Albion)	2.3 miles	Class B	Aquatic Life	Dissolved Oxygen, Agricultural Non-Point Source
	Fish Brook (Fairfield)	4.9 miles	Class B	Aquatic Life	Aquatic Life Criteria, Agricultural Non-Point Source, Habitat Degradation

Watershed	Segment Name	Segment Size	Segment Class	Impaired Use	Causes and Potential Sources
Kennebec River	Jock Stream (Wales)	4.8 miles	Class B	Aquatic Life	Dissolved Oxygen, Nutrients, Agricultural Non-Point Source
	Mill Stream (Winthrop)	1.4 miles	Class B	Aquatic Life	Aquatic Life Criteria, Urban Non-Point Source, Habitat Degradation
	Unnamed tributary to Bond Brook (Augusta) entering below I-95	2.0 miles	Class B	Aquatic Life	Aquatic Life Criteria, Urban Non-Point Source
	Meadow Brook (Farmingdale)	1.0 miles	Class B	Aquatic Life	Aquatic Life Criteria, General Development Non-Point Source
	Currier Brook	3.2 miles	Class B	Recreation	Bacteria, Urban Non-Point Source
	Whitney Brook (Augusta)	2.7 miles	Class B	Recreation	Bacteria, Urban Non-Point Source
	Sebasticook Lake	4,288 acres	Na	Recreation	Nutrients, Urban Non-Point Sources and Agricultural Non-Point Source
	China Lake	3,845 acres	Na	Recreation	Nutrients, Urban Non-Point Sources and Agricultural Non-Point Source
	East Pond	1,823 acres	Na	Recreation	Nutrients, Urban Non-Point Sources
	Annabessacook Lake	1,420 acres	Na	Recreation	Nutrients, Urban Non-Point Sources and Agricultural Non-Point Source

Watershed	Segment Name	Segment Size	Segment Class	Impaired Use	Causes and Potential Sources
Kennebec River	Pleasant Pond (Mud)	746 acres	Na	Recreation	Nutrients, Dissolved Oxygen; Urban Non-Point Sources and Agricultural Non-Point Source
	Cobbosseecontee Lake	5,543 acres	Na	Recreation	Nutrients, Urban Non-Point Sources and Agricultural Non-Point Source
	Threecornered Pond	182 acres	Na	Recreation	Nutrients, Urban, Forestry, and Agricultural Non-Point Sources
	Threemile Pond	1,162 acres	Na	Recreation Fishing	Nutrients, Dissolved Oxygen; Urban, Forestry, and Agricultural Non-Point Sources
	Webber Pond	1,201 acres	Na	Recreation Fishing	Nutrients, Dissolved Oxygen; Urban, Forestry, and Agricultural Non-Point Sources
	Toothaker Pond	30 acres	NA	Recreation (Primary Contact)	Needs Total Maximum Daily Load Report
	Lovejoy Pond	324 acres	NA	Recreation (Primary Contact)	Needs Total Maximum Daily Load Report
	Unity Pond	2,528 acres	NA	Recreation (Primary Contact)	Needs Total Maximum Daily Load Report
	Cobbosseecontee Lake Tributaries	75 acres	NA	Recreation (Primary Contact)	Needs Total Maximum Daily Load Report
	Narrows Pond (Upper)	279 acres	NA	Dissolved Oxygen	Needs Total Maximum Daily Load Report
	Togus Pond	660 acres	NA	Recreation (Primary Contact)	Needs Total Maximum Daily Load Report

Watershed	Segment Name	Segment Size	Segment Class	Impaired Use	Causes and Potential Sources
Kennebec River	Kennebec River Estuary and Tributaries	17,294 acres	SB	Recreation (Primary Contact)	Bacteria; Elevated fecals; Nonpoint Sources
	Lower Kennebec River Estuary, Phippsburg /Georgetown	2,208 acres	SB	Recreation (Primary Contact)	Bacteria; Elevated fecals; Nonpoint Sources , Combined Sewer Overflows Overboard Discharges
Androscoggin River	Aziscohos Lake	6,700 acres	NA	Aquatic Life	Lake draw down
	Androscoggin River, main stem, from Maine-NH border to Wild River	2.4 miles	Class B	Fishing (Consumption)	Industrial Point Sources (Dioxin)
	Androscoggin River, main stem, above Rumford Point	31 miles	Class B	Fishing (Consumption)	Industrial Point Sources (Dioxin)
	Androscoggin River, main stem, from Rumford Pt to Nezinscot River	55.2 miles	Class C	Fishing (Consumption)	Industrial Point Sources (Dioxin)
	House/Lively Brook	3.5 miles	Class B	Aquatic Life	Agricultural Non-Point Sources Waste Removal (Manure)
	Androscoggin River, main stem, from confluence of Nezinscot R toGreat Falls in Little Androscoggin River	15.5 miles	Class C	Fishing (Consumption) Recreation	Industrial Point Sources (Dioxin) Bacteria-Combined Sewer Overflows, Mechanic Falls, Lewiston-Auburn including Hart Brook
	Little Androscoggin River at Mechanic Falls			Recreation	Bacteria-Combined Sewer Overflows
	Androscoggin R, main stem, from Little Androscoggin River to Brunswick-Bath boundary	30.7 miles	Class C	Fishing (Consumption)	Industrial Point Sources (Dioxin)

Watershed	Segment Name	Segment Size	Segment Class	Impaired Use	Causes and Potential Sources
Androscoggin River	Sabattus Pond	1,962 acres	NA	Recreation (Primary Contact)	Needs Total Maximum Daily Load Report
Maine Coastal	Dennys River, Meddybemps Lake to Dead Stream	4.5 miles	Class AA	Aquatic Life Fishing (Consumption)	Hazardous Waste Remediation Project (Superfund)
	Great Falls Branch, Schoodic Stream (Deblois)	2.0 miles	Class A	Aquatic Life	Aquatic Life Criteria, Agricultural Non-Point Sources
	Card Brook (Ellsworth)	0.6 miles	Class B	Aquatic Life Recreation	Dissolved Oxygen, Bacteria, Non-Point Source, (unspecified)
	Carleton Stream (Blue Hill)	1.3 miles	Class C	Aquatic Life	Aquatic Life Criteria, Metals Mine Waste
	Warren Brook (Belfast)	6.3 miles	Class B	Aquatic Life	Dissolved Oxygen, Non-Point Source, (unspecified)
	Pottle Brook (Perry)	0.5 miles	Class B	Recreation	Bacteria, Unknow Untreated waste, Non-Point Source (Unspecified)
	Megunticook River (Camden)	3.6 miles	Class B	Recreation	Bacteria, Urban Non-Point Source
	Unnamed Brook (Rockport)	0.5 miles	Class B	Recreation	Bacteria, Urban Non-Point Source
	Unnamed Brook (Rockland)	0.5 miles	Class B	Recreation	Bacteria, Urban Non-Point Source
	Unnamed Brook (Camden)	0.7 miles	Class B	Recreation	Bacteria, Urban Non-Point Source
	McCoy Brook (Deblois)	1.0 miles	Class B	Aquatic Life	Aquatic Life criteria, pH, - Non-Point Source – Abandoned Peat Mining
	Graham Lake	7,865 acres	NA	Aquatic Life	Lake draw down

Watershed	Segment Name	Segment Size	Segment Class	Impaired Use	Causes and Potential Sources
Maine Coastal	Lilly Pond	29 acres	NA	Recreation (Primary Contact)	Needs Total Maximum Daily Load Report
	Eastern Wheeler Bay, Tenants Harbor to Mosquito Head, and Marshall Point - Mosquito Head, St. George	833.1 acres	SB	Recreation (Primary Contact)	Bacteria; OBDs; Septic system problems; Elevated fecals; Nonpoint Source
	Weskeag River, South Thomaston and Owls Head	9.8 acres	SB	Recreation (Primary Contact)	Bacteria; Septic system problems; Elevated fecals; Nonpoint Source
	Rockland Harbor	2,459.9 acres	SB/SC	Recreation (Primary Contact)	Sewage Treatment Plant; Overboard Discharges; Stormwater; Boats; Elevated fecals; Nonpoint Source
	Rockport Harbor	2,036.3 acres	SB	Recreation (Primary Contact)	Bacteria; Boats, Overboard Discharges, Elevated fecals, Nonpoint Source
	Vinalhaven Harbor, Roberts Harbor, Vinal Cove - Starboard Rock, Vinalhaven	1,520.9 acres	SB	Recreation (Primary Contact)	Bacteria; Boats, Elevated fecals, Nonpoint Source, and Overboard Discharges
	Kent Cove and Southern Harbor, North Haven	217.4 acres	SB	Recreation (Primary Contact)	Bacteria; Elevated fecals, Nonpoint Source
	Searsport - Stockton Springs	2,832.7 acres	SB/SC	Recreation (Primary Contact)	Bacteria; Sewage Treatment Plant, Overboard Discharges, Septic system Problems, Elevated fecals, Nonpoint Source

Watershed	Segment Name	Segment Size	Segment Class	Impaired Use	Causes and Potential Sources
Maine Coastal	Stonington Harbor, Western Cove, Stinson Neck, & NW Branch of Crocket Cove, Deer Isle & Stonington	240 acres	SB	Recreation (Primary Contact)	Bacteria; Overboard Discharges, Elevated fecals, Nonpoint Source
	Rockport Harbor to Ducktrap Harbor, Lincolnville	2,139.6 acres	SB	Recreation (Primary Contact)	Bacteria; Sewage Treatment Plant, Elevated fecals, Nonpoint Source
	Great Spruce Head - Kelleys Cove,Northport	1,237.3 acres	SB	Recreation (Primary Contact)	Bacteria; Sewage Treatment Plant, Elevated fecals, Nonpoint Source
	Center Harbor - Brooklin and Eastern Flye Point, Brooklin	43 acres	SB	Recreation (Primary Contact)	Bacteria; Elevated fecals, Nonpoint Source
	Benjamin River, Sedgwick and Salt Pond, Sedgwick - Brooklin	118 acres	SB	Recreation (Primary Contact)	Bacteria; Seasonal marina, Elevated fecals, Nonpoint Source
	Bass Harbor & Eastern Duck Cove,Tremont	702.0 acres	SB	Recreation (Primary Contact)	Bacteria; Overboard Discharges, Elevated fecals, Nonpoint Source
	Mackerel Cove, Swans Island	4.0 acres	SB	Recreation (Primary Contact)	Bacteria; Elevated fecals, Nonpoint Source
	Goose Cove, Trenton	121.0 acres	SB	Recreation (Primary Contact)	Bacteria; Elevated fecals; Nonpoint Source
	Pretty Marsh Harbor, Mount Desert	180.0 acres	SB	Recreation (Primary Contact)	Bacteria; Elevated fecals; Nonpoint Source
	Tinker Brook (Goose Cove), West Tremont	9.0 acres	SB	Recreation (Primary Contact)	Bacteria; Elevated fecals; Nonpoint Source
	Thomas Bay and Bar Harbor, Bar Harbor Elevated fecals; Nonpoint Source	10.0 acres	SB	Recreation (Primary Contact)	Bacteria; Elevated fecals; Nonpoint Source and Combined Sewer Overflows

Watershed	Segment Name	Segment Size	Segment Class	Impaired Use	Causes and Potential Sources
Maine Coastal	Jellison Cove, Kilkenny Cove and Carrying Place, Hancock	77.0 acres	SB	Recreation (Primary Contact)	Bacteria; Elevated fecals; Nonpoint Source
	U.S.Rt. 1 Bridge, West Sullivan and Long Cove, Sullivan Current	30.0 acres	SB	Recreation (Primary Contact)	Bacteria; Elevated fecals; Nonpoint Source
	Springer Brook, Mill Brook and West Brook, West Franklin	93.0 acres	SB	Recreation (Primary Contact)	Bacteria; Elevated fecals; Nonpoint Source
	Johnny's Brook and Card Mill Stream,Franklin	2.0 acres	SB	Recreation (Primary Contact)	Bacteria; Elevated fecals; Nonpoint Source
	Egypt Bay, Hancock & Franklin	106.0 acres	SB	Recreation (Primary Contact)	Bacteria; Elevated fecals; Nonpoint Source
	Mill Pond Stream and Birch Harbor, Gouldsboro	27.0 acres	SB	Recreation (Primary Contact)	Bacteria; Elevated fecals; Nonpoint Source, Seasonal Marina
	Dyer Harbor - Pinkham Bay, Steuben	73.0 acres	SB	Recreation (Primary Contact)	Bacteria; Elevated fecals; Nonpoint Source
	Tucker Creek, Gouldsboro and Steuben Harbor	44.0 acres	SB	Recreation (Primary Contact)	Bacteria; Elevated fecals; Nonpoint Source
	Dyer Harbor, Steuben	162.0 acres	SB	Recreation (Primary Contact)	Bacteria; Elevated fecals; Nonpoint Source
	Mitchell Point, Smith Cove, Narraguagus Bay, and Back Bay, Milbridge	88 acres	SB	Recreation (Primary Contact)	Bacteria; Septic system problems; Elevated fecals; Nonpoint Source
	Curtis Creek, Flat Bay, and Upper Harrington River, Harrington	514 acres	SB	Recreation (Primary Contact)	Bacteria; Elevated fecals; Nonpoint Source

Watershed	Segment Name	Segment Size	Segment Class	Impaired Use	Causes and Potential Sources
Maine Coastal	Jonesport and West Jonesport	595.0 acres	SB	Recreation (Primary Contact)	Bacteria; Overrboard Discharges; Elevated fecals; Nonpoint Source
	North End of Beals Island	149.0 acres	SB	Recreation (Primary Contact)	Bacteria; Elevated fecals; Nonpoint Source
	Indian River, Addison - Jonesport	68.0 acres	SB	Recreation (Primary Contact)	Bacteria; Elevated fecals; Nonpoint Source
	Southeastern Alley Bay & Pig Island Gut, Beals	24.0 acres	SB	Recreation (Primary Contact)	Bacteria; Elevated fecals; Nonpoint Source
	Lamesen Brook in West River, Addison	52.0 acres	SB	Recreation (Primary Contact)	Bacteria; Elevated fecals; Nonpoint Source
	East & West Branches, Little Kennebec Bay, Machias and Machiasport	68.0 acres	SB	Recreation (Primary Contact)	Bacteria; Elevated fecals; Nonpoint Source
	Machias, Waste Water Treatment Facility		SB	Recreation (Primary Contact)	Bacteria; Combined Sewer Overflows
	White Creek, Masons Bay, Jonesport – Jonesboro	47.0 acres	SB	Recreation (Primary Contact)	Bacteria; Elevated fecals; Nonpoint Source
	Indian Head, Machiasport	17.0 acres	SB	Recreation (Primary Contact)	Bacteria; Elevated fecals; Nonpoint Source
	Little River - Cutler Harbor	37.0 acres	SB	Recreation (Primary Contact)	Bacteria; Elevated fecals; Nonpoint Source
	Money Cove, Cutler	32.0 acres	SB	Recreation (Primary Contact)	Bacteria; Elevated fecals; Nonpoint Source
	Haycock Harbor, Trescott	16.0 acres	SA/SB	Recreation (Primary Contact)	Bacteria; Elevated fecals; Nonpoint Source
	Lubec and South Lubec	557.0 acres	SB	Recreation (Primary Contact)	Bacteria; Overboard Discharges, Elevated fecals; Nonpoint Source

Watershed	Segment Name	Segment Size	Segment Class	Impaired Use	Causes and Potential Sources
Maine Coastal	Denny's River and Northwest Denny's Bay, Edmunds – Pembroke	88.0 acres	SA/SB	Recreation (Primary Contact)	Bacteria; Elevated fecals; Nonpoint Source
	Pennamaquan Bay, Pembroke	80.0 acres	SB	Recreation (Primary Contact)	Bacteria; Elevated fecals; Nonpoint Source
	East Stream, Trescott	15.0 acres	SA/SB	Recreation (Primary Contact)	Bacteria; Elevated fecals; Nonpoint Source
	Canal Cove, Seward Neck, Lubec	47.0 acres	SB	Recreation (Primary Contact)	Bacteria; Elevated fecals; Nonpoint Source
	Sipp Bay, Perry and Robinston	54.0 acres	SB	Recreation (Primary Contact)	Bacteria; Elevated fecals; Nonpoint Source
	Deep Cove, Eastport	154.0	SC	Recreation (Primary Contact)	Bacteria; Elevated fecals; Nonpoint Source
	The Haul-Up, South Bay, West Lubec	40.2	SB	Recreation (Primary Contact)	Bacteria; Elevated fecals; Nonpoint Source
Saint George and Sheepscot Rivers	West Branch Sheepscot River below Halls Corner	4.0 miles	Class AA	Aquatic Life	Dissolved Oxygen, Agricultural Non-Point Source,
	Sheepscot River below Sheepscot Lake	4.0 miles	Class B	Aquatic Life	Dissolved Oxygen, Aquaculture Point Source
	Dyer River below Route 215	6.0 miles	Class B	Aquatic Life Recreation	Dissolved Oxygen, Bacteria, Agricultural Non-Point Source,
	Trout Brook (Alna)	2.3 miles	Class B	Aquatic Life	Dissolved Oxygen, Non-Point Source, (unspecified)
	Meadow Brook (Whitefield)	5.0 miles	Class B	Aquatic Life	Dissolved Oxygen, Non-Point Source, (unspecified)
	Carlton Brook (Whitefield)	2.8 miles	Class B	Aquatic Life	Dissolved Oxygen, Non-Point Source, (unspecified)

Watershed	Segment Name	Segment Size	Segment Class	Impaired Use	Causes and Potential Sources
Saint George and Sheepscot Rivers	Choate Brook (Windsor)	1.3 miles	Class B	Aquatic Life	Dissolved Oxygen, Non-Point Source, (unspecified)
	Chamberlain Brook (Whitefield)	2.0 miles	Class B	Aquatic Life	Dissolved Oxygen, Non-Point Source, (unspecified)
	Sheepscot River at Alna	4.0 miles	Class AA	Recreation	Bacteria, Unknow Untreated waste, Non-Point Source (Unspecified)
	Duckpuddle Pond	293 acres	NA	Recreation (Primary Contact)	Needs Total Maximum Daily Load Report
	Sewall Pond	46 acres	NA	Recreation (Primary Contact)	Needs Total Maximum Daily Load Report
	Back River, Wiscasset and Westport	139.4 acres	SB	Recreation (Primary Contact)	Bacteria; Elevated fecals; Nonpoint Sources , OBDs
	Western Barters Island, Boothbay	225.9 acres	SB	Recreation (Primary Contact)	Bacteria; Elevated fecals; Nonpoint Source
	Ovens Mouth - Sherman Creek, Boothbay – Edgecomb	162.3 acres	SB	Recreation (Primary Contact)	Bacteria; Elevated fecals; Nonpoint Source
	Ebencook Harbor, Southport	1351.2 acres	SB	Recreation (Primary Contact)	Bacteria; Overboard Discharges; Boats; Elevated fecals;Nonpoint Source
	Great Bay	516.1 acres	SB	Recreation (Primary Contact)	Bacteria; Elevated fecals; Nonpoint Source
	Damariscotta River, Newcastle – Damariscotta	169.1 acres	SB	Recreation (Primary Contact)	Bacteria; Sewage Treatment Plant; Elevated fecals; Nonpoint Source

Watershed	Segment Name	Segment Size	Segment Class	Impaired Use	Causes and Potential Sources
Saint George and Sheepscot Rivers	Medomak River, Waldoboro and Friendship	334 acres	SB	Recreation (Primary Contact)	Bacteria, Dissolved Oxygen; Elevated fecals after rainfall; Nonpoint Source, Combined Sewer Overflow
	Monhegan Island	521.6 acres	SB	Recreation (Primary Contact)	Bacteria; Untreated household sewage (straight pipe)
	Saint George River Estuary	1576.7 acres	SB	Recreation (Primary Contact)	Bacteria, Dissolved Oxygen; Elevated fecals after rainfall; Nonpoint Source, Combined Sewer Overflow, OBDs, Septic system problems