

Habitat requirements and management considerations for Atlantic salmon
(*Salmo salar*) in the Gulf of Maine Distinct Population Segment (GOM
DPS)

DRAFT

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Table of Contents

Executive Summary	1
Section 1: Introduction	2
Section 2: Ecosystem processes.....	3
2.1 Hydrology.....	3
2.2 Geomorphology.....	4
2.2.1 <i>Physical Habitat</i>	4
2.3 Riparian zones	6
2.4 Water Quality	6
2.4.1 <i>Temperature</i>	6
2.4.2 <i>Dissolved oxygen</i>	7
2.4.3 <i>Nutrients</i>	7
2.4.4 <i>pH</i>	8
2.4.5 <i>Dissolved organic carbon</i>	8
2.5 Connectivity	9
2.5.1 <i>Nutrient cycling and transport</i>	10
2.5.2 <i>Biotic interactions</i>	11
Section 3: Ecological disturbances	16
3.1 Changes in hydrology.....	17
3.2 Changes in geomorphology.....	18
3.2.1 <i>Physical habitat</i>	18
3.3 Changes in riparian zones.....	20
3.4 Changes in water quality	20
3.4.1 <i>Temperature</i>	20
3.4.2 <i>Nutrients and dissolved oxygen</i>	21
3.4.3 <i>pH</i>	21
3.4.4 <i>Dissolved organic carbon</i>	22
3.5 Changes in connectivity.....	23
3.5.1 <i>Nutrient cycling and transport</i>	23
3.5.2 <i>Biotic interactions</i>	24
Section 4: Lifestage specific habitat features utilized by Atlantic salmon.....	26
4.1 Adults.....	26
4.1.1 <i>Adult freshwater migration</i>	27
4.1.2 <i>Temperature and oxygen requirements</i>	28
4.1.3 <i>Flow and depth requirements</i>	29

4.1.4 Diadromous fish interactions	30
4.2 Spawning	30
4.2.1 Substrate and redd formation	31
4.2.2 Egg pit depth and substrate permeability	31
4.2.3 Water depth and velocity	32
4.2.4 Spawning temperature and timing	33
4.2.5 pH	33
4.2.6 Cover	34
4.2.7 Space	34
4.2.8 Fisheries interactions	34
4.3 Embryo development and larval fry	35
4.3.1 Temperature	35
4.3.2 Dissolved oxygen	36
4.3.3 pH	37
4.3.4 Metals	37
4.3.5 Food	37
4.3.6 Emergence and territory development	38
4.4 Parr	39
4.4.1 Space and cover	39
4.4.2 Mesohabitat and substrate preferences	40
4.4.3 Velocity	42
4.4.4 Temperature	42
4.4.5 Dissolved Oxygen	43
4.4.6 Sediments	44
4.4.7 Food	44
4.5 Smoltification	45
4.5.1 Photoperiod, temperature and flow	46
4.5.2 Water chemistry	47
4.5.3 Olfactory imprinting	48
4.5.4 Migration requirements	48
4.6 Marine Habitat	49
4.6.1 Post smolt migration and behavior	49
4.6.2 Estuary influence on adult returns	50
4.6.3 Temperature and climate	50
4.7 Kelts	51
Section 5: Human activities that affect habitat features	52
5.1 Effects of dams	52
5.1.1 Configuration of dams in the Gulf of Maine DPS	52
5.1.2 Fish Passage	56
5.1.3 Physical habitat	57
5.1.4 Sediment transport	57
5.1.5 Stream temperature	57
5.1.6 Stream flow and water levels	58
5.1.7 Disease	58
5.1.8 Water Chemistry	58
5.2 Effects of contaminants	58

5.2.1 Biota	59
5.3 Effects of agriculture	60
5.3.1 Physical habitat	62
5.3.2 Hydrology	62
5.3.3 Water quality	63
5.4 Effects of Forestry	64
5.4.1 Historical perspective and significance to Atlantic salmon habitat	65
5.4.2 Forestry today	67
5.4.3 Hydrology	67
5.4.4 Water quality	68
5.4.5 Stream temperature	69
5.4.6 Nutrients	69
5.4.8 Physical habitat	69
5.5 Effects of Changing Land-Use Patterns/Development	70
5.5.1 Sediment transport and physical habitat	72
5.5.2 Water quality and chemistry	72
5.5.3 Stream biota	73
5.6 Effects of roads and road crossings.....	74
5.6.1 Sedimentation	75
5.6.2 Physical structure	75
5.6.3 Water quality and stream flow	77
5.6.4 Fish passage	77
5.7 Effects of mining	77
5.7.1 Habitat and sedimentation	78
5.7.2 Water chemistry	78
5.7.3 Atlantic salmon physiology	78
5.8 Effects of hatcheries and stocking	78
5.8.1 Atlantic salmon	79
5.8.2 Species interactions	79
5.9 Effects of anthropogenic acidification	79
5.9.1 Water chemistry	81
5.10 Effects of global climate change	82
5.10.1 Water temperature	83
5.10.2 Atlantic salmon	83
5.11 Effects of aquaculture	84
5.11.1 Atlantic salmon	84
Disease and Parasites	85
5.11.2 Habitat	86
5.12 Effects of Chemically Treated Construction Materials.....	86
5.13 Effects of Dredging	87
5.13.1 Water quality	88
5.13.2 Fish communities	89
5.14 Effects of Shoreline Armoring.....	89

5.14.1 Habitat	90
5.14.2 Behavior	90
5.15 Effects of Pilings, Piers, and Overwater Structures	91
5.15.1 Habitat	91
5.15.2 Behavior	92
5.15.3 Water flow	93
5.16 Effects of Breakwaters	93
5.16.1 Behavior	93
5.17 Effects of Tide Gates	94
5.18 Effects of Beach Nourishment	94
5.18.1 Habitat	94
5.19 Effects of Marinas.....	94
5.19.1 Habitat	95
5.19.2 Water Quality	95
Literature Cited	96

Executive Summary

Atlantic salmon (*Salmo salar*) throughout most of their range have experienced dramatic declines in abundances over recent decades. Declines through much of North America are believed to be largely attributed to the construction of dams and over fishing. Dams and poor marine survival have been identified as the biggest obstacle to recovery while numerous other threats including pollution, sedimentation, road crossings, and anthropogenic acidification have also been identified as factors that reduce the quality and quantity of habitat available to the species. U.S. populations have been extirpated from much of their historic range. The only remaining wild population of Atlantic salmon are those in the Gulf of Maine Distinct Population Segment (GOM DPS). This includes all Atlantic salmon from the Androscoggin River in south central Maine north and east to the Dennys River in far eastern Maine. The Atlantic salmon of the GOM DPS are currently faced with the threat of extinction and have subsequently been listed under the Endangered Species Act (ESA).

The Endangered Species Act requires that critical habitat be designated concurrently with making the determination that a species is endangered or threatened. Critical habitat designations provide additional protections beyond classifying a species as either threatened or endangered, by avoiding the destruction or adverse modification of the physical and biological features essential for the conservation of the species. The ESA requires that any proposed Federal actions not adversely modify or destroy designated critical habitat.

This document presents a review of the habitat features that Atlantic salmon utilize and reviews activities and threats that may affect those features. This document is only designed to provide supporting information needed to designate critical habitat for Atlantic salmon in the GOM DPS and does not specifically adhere to the guidelines for designating critical habitat in the ESA. In total, this document is broken into five sections, each of which describes various ecological concepts and components essential to the conservation of the species. Sections 2 & 3 review the role ecological processes and disturbances that influence Atlantic salmon behavior and biology as well the role that ecosystem process and disturbances play on the evolution of the species. Section 4 is a discussion of the lifestage specific habitat features that Atlantic salmon utilize based upon research conducted over the last century, while section 5 identifies activities and threats that affect those habitat features.

Section 1: Introduction

Atlantic salmon have a complex life history that ranges from territorial rearing in rivers to extensive feeding migrations on the high seas. During their life cycle Atlantic salmon go through several distinct phases that are identified by specific changes in behavior, physiology, morphology, coloration, and habitat requirements. Atlantic salmon are quite capable of surviving in and adapting to a wide range of habitat types and their success as a species is determined by their ability to adapt to and utilize an array of foraging and defensive strategies that maximize survival. Juvenile salmon have been documented utilizing riverine, lake, and estuarine habitats; incorporating opportunistic and active feeding strategies; defending territories from competitors including other parr; and working together in small schools to actively pursue prey.

Over the past two centuries exploitations, alterations of habitat through construction of dams, land use and development practices, fisheries management practices, alteration of predator prey interactions through exotic fish introductions (e.g. smallmouth bass (*Micropterus dolomieu*) and brown trout (*Salmo trutta*)), and possible changes in climatic conditions have outpaced the rate in which salmon can adapt. As a result, many areas of once productive habitat are no longer capable of supporting healthy populations of Atlantic salmon in the abundances needed for their continued existence into the foreseeable future. Further assessment of these habitat alterations is needed to fully understand the recent declines in salmon abundance.

Spence *et al.* (1996) suggest that there are four principles that must be considered when assessing the habitat of salmonids: 1) All watersheds and all streams are different to some degree whether it be temperature regimes, flow regimes, differences in sediment rates, nutrient fluxes, or physical and biological features; 2) the fish populations within these streams have adapted physiologically, biochemically, morphologically, and behaviorally to the differences that they experience and to the biota with which they share a stream, lake, or estuary; 3) the specific habitat requirements of salmonids differ among salmonid species and their life history types, and change with season, life stage, and the presence of other biota; and 4) aquatic ecosystems change over evolutionary time.

These principles are applied to describe the physical and biological features essential to the conservation of the Gulf of Maine Distinct Population Segment (GoM DPS) of Atlantic salmon. One significant challenge is that salmon related studies and research conducted to identify Atlantic salmon habitat needs have been conducted since after habitat alterations and exotic species introductions. This provides an incomplete picture of the actual diversity of the niche that salmon occupy and the importance of those niches in a salmon's life history and ultimately their role in population recovery. The following sections detail the life history typical of Atlantic salmon originating from U.S. rivers, including the ecosystem processes, habitat features, and life-stage specific requirements that are essential for the conservation of the GoM DPS of Atlantic salmon.

Section 2: Ecosystem processes

Ecosystems function as complete units. If one component is removed or altered, a cascade of ecological impacts may occur throughout the remaining system. Many researchers believe that certain organisms present within an ecosystem (*i.e.* keystone species) may play a vital role in controlling and maintaining population structure and dynamics (Paine 1969, Estes and Palmisano 1974, Mills *et al.* 1993). A differing theory is that ecosystem function is controlled by compartments, or groupings of organisms, that may increase stability in networks such as food webs (Krause *et al.* 2003). No matter how you choose to view an ecosystem, it is clear that they function through an intricate web of physical, chemical, and biotic interactions, each of which may be equally as important as the next in determining the overall health and function of the ecosystem and therefore, its ability to sustain a robust Atlantic salmon population. In essence, healthy Atlantic salmon populations require properly functioning ecosystems that “have the ability to support and maintain a balanced, integrated adaptive community of organisms having a species composition, diversity, and functional organization comparable to that of the natural habitat of the region” (Karr 1991). The following section will describe the five components of a riverine ecosystem (*i.e.* hydrology, geomorphology, biology, water quality, and connectivity; Annear *et al.* 2004) and how these components fit in the context of ecological processes occurring at the watershed level and their potential influence on Atlantic salmon survival and fitness. Additionally, processes occurring in the estuarine and marine environments that may influence Atlantic salmon population dynamics will be described.

2.1 Hydrology

The hydrology of a stream ecosystem can significantly influence its morphology as well as the composition of species present within the system. Variability in flows can create and maintain dynamic channel and floodplain conditions. High flows have the ability to sort and transport sediments, create discrete distributions of different-sized particles, move bed material, provide a sediment balance, control submerged, emergent, and streamside vegetation, influence the structural stability of stream banks, and prevent vegetation encroachment in the active channel (Annear *et al.* 2004). Whereas, low flows may reduce inundation of the riparian habitat, allow for encroachment of riparian vegetation, and reduce sediment dynamics and physical processes occurring within the river system. Natural variability in flow creates essential habitats for aquatic and riparian species, and directly regulates numerous ecological processes (Annear *et al.* 2004). Many organisms present within and around riverine ecosystems have evolved life cycles which are timed to either avoid or exploit flows of variable magnitudes (Annear *et al.* 2004). Variation in flow is the key component in a riverine ecosystem that has the ability to drive processes that periodically reset physical, chemical, and biological functions essential to the ecosystem (Annear *et al.* 2004). Seasonal variation in flow, including drought, can prevent the successful establishment of nonnative species with specific moisture requirements or inundation tolerances whereas predictable high and low stream flow may provide cues for certain life cycle events (*i.e.* spawning movements, egg hatching, and upstream and downstream migration) (Annear *et al.* 2004).

It is important to recognize that the physical habitat essential to maintaining the aquatic community is formed by periodic disturbance, which, in the short-term, may be detrimental to the growth and survival of individual fish or entire year classes of fish (Annear *et al.* 2004). Over the long-term periodic disturbances that reset the system by forming new channels in some instances, scouring vegetation and fine sediments, abandoning side channels, and creating habitat, are beneficial for native species (Annear *et al.* 2004).

2.2 Geomorphology

The morphology of a watershed can play a significant role in material processing as well as providing physical habitat to resident organisms. Geomorphology and material processing functions of watersheds can be divided into three distinct zones. The headwaters are considered to be the zone of production where most of the sediments, organic matter, nutrients, and water load of the river are acquired (Schuum 1977; Chamberlin *et al.* 1991; Murphy 1995). The middle and lower reaches of the river are considered to be the zone of transfer. In the zone of transfer, transport and channel building processes dominate (Schuum 1977). The mouth of the river is considered to be the zone of deposition (Schuum 1977).

Within a watershed there can be a wide variety of habitat niches available to Atlantic salmon. These niches range from large main-stem reaches which serve as primary migration corridors down to first order streams that can be used for spawning and intermittent rearing of early juvenile life stages. Any one of these niches may be a vital component necessary for the completion of various stages of the Atlantic salmon's complex life cycle. As juveniles, Atlantic salmon can be found throughout an entire watershed, typically hatching and rearing in smaller headwater streams and eventually migrating out to the marine environment. As adults, the spawning migration leads Atlantic salmon back into a watershed where they eventually find their way to suitable spawning habitat. Salmonids most frequently select second to fourth order streams for spawning and rearing (Chamberlin *et al.* 1991). Due to the diversity and abundance of small streams present in a watershed, they may play a critical role in maintaining the integrity of the freshwater riverine ecosystem. Murphy (1995) describes small streams as the "backbone" of salmonid habitat even if the streams are unoccupied or intermittent. Often times these small stream channels account for over half of the total stream length of a watershed (Murphy 1995). In addition, the small first, second, and third order streams play a vital role in regulating the quality of downstream habitats by carrying sediment, nutrients, and woody debris from the upper portions of the watershed (Chamberlin *et al.* 1991, Murphy 1995).

2.2.1 Physical Habitat

The presence or absence of certain physical features such as pools, side-channels, backwaters, undercut banks, boulders, and organic and woody debris is often dictated by the surrounding geological and climatic characteristics. The uniqueness of these features is primarily determined by the associated hill slope and riparian vegetation (Sullivan *et al.* 1987). Physical features often provide refugia for many riverine fish species, including Atlantic salmon. In addition, these physical features play a significant role in

determining habitat quality and quantity. Physical features can enhance habitat complexity, thereby improving the diversity of habitats present, many of which are needed to support salmon populations. Two of the primary constituents of physical habitat, large woody debris and boulders, can play an important role in sediment dynamics and thereby inherently help define channel morphology.

Large Woody Debris

In a riverine ecosystem, the presence of in-stream large woody debris (LWD) can increase channel complexity while helping create high-quality pools and riffles (Platts 1991) that provide habitat for feeding, rearing and cover for juvenile and adult salmon. The presence of LWD in a riverine system is believed to have significant impacts on the species composition and abundance. Juvenile Atlantic salmon are believed to utilize pools and LWD for refuge as they get older, particularly during the winter (Cunjak *et al.* 1998). Systems with relatively low inputs of LWD typically have lower densities of salmonids. This decline in salmonid abundance is thought to be associated with a decrease in channel complexity; a decrease in the number and volume of pools; a reduction in the quality of cover; and a reduction in the capacity of a river or stream to store and process organic matter (Hicks *et al.* 1991), all of which may be a result of reduced availability of in-stream LWD.

Boulders

Boulders in streams cause localized obstruction to flow generating an eddy or backwater that creates a scour hole on the boulders downstream side (Calkins 1988). Backwaters and scour holes are used by salmonids for resting, shelter and feeding. Boulders may be particularly important for over wintering fish. The formation of ice in streams results in the re-organization and redistribution of physical space and habitat availability for over wintering fish (Whalen *et al.* 1999a). Calkins (1988) noted that rivers containing numerous large boulders or have narrow stream channels tend to keep ice in its original freeze up position, even if water levels should fall through the winter. Ice sheets that fail at the stream bank due to diminished flows have the potential to reduce available habitat. During reduced flows, boulders can physically support the ice and allow for the formation of air pockets acting as an insulating layer that prevents freezing of the substrate (Calkins 1988). Whalen *et al.* (1999a) conducted a study on the Rock River in Connecticut to determine how ice affects selection of habitats and distribution of post-young-of-the-year Atlantic salmon parr. They found that rock and root wad complexes were key structural elements used to support high concentrations of parr relative to other areas during ice and post ice periods.

Sedimentation

For many rivers in their natural state, channel forming processes function in a state of dynamic equilibrium where sediment load is in balance with a rivers capacity to transport sediments over time (Bovee *et al.* 1998). The combination of discharge and sediment load can influence channel morphology (Murphy and Meehan, 1991). When sediment loads exceed a rivers transport capacity, aggregation of sediments can occur and may cause substrates to become embedded. When transport capacity exceeds sediment loads, stream channels may adjust through stream channel widening, or streambed degradation

(Annear *et al.* 2004). The transport of sediments and organic matter from the headwaters plays a vital role in the proper functioning of the entire watershed and has strong influences on channel morphology and habitat availability within a river system.

2.3 Riparian zones

Riparian zones serve a variety of ecological functions including bank stabilization, control of material movement, regulation of streamside microclimates, filtration of nutrients, and inputs of allochthonous material such as leaves, needles and woody debris (Elliott *et al.* 1998, Murphy and Meehan 1991). The food energy that salmon rely on is largely dependent upon aquatic and riparian plant communities. Plants convert solar energy into biomass, making it available in the form of organic matter. In turn, this organic matter provides the energy base needed to support higher trophic levels ultimately providing nutrients needed to sustain aquatic invertebrate communities (Spence *et al.* 1996) upon which juvenile salmon and other native fish species are dependent. In addition, vegetated riparian areas support terrestrial insects that may serve as forage to juvenile Atlantic salmon and other fish when they fall in the stream.

Forested riparian zones can provide a protective canopy that helps regulate stream temperatures both in the summer and winter (Murphy and Meehan 1991). Riparian zones also influence the abundance of large woody vegetation, potentially providing habitat structure and bank stability to streams through root system development and woody debris contributions (Murphy and Meehan 1991). Riparian brush and shrubs can provide low overhanging bank cover that provides shelter to fish and helps maintain bank stability. Grasses and herbaceous plants can also help build and bind bank materials; further reducing erosion (Platts 1991).

2.4 Water Quality

Water quality plays an important role in the physiological health of Atlantic salmon and can influence survival, behavior, reproduction, and resistance to disease and predation. The water chemistry within a particular watershed is largely influenced by geology, geomorphology and hydrodynamics of the system. These physical features determine the soil's and water's acid neutralizing capacity (ANC), resistance to surface water change in pH, and ability to absorb metals and organic compounds (Haines 1981), as well as temperature, turbidity, nutrient loads and dissolved oxygen content.

2.4.1 Temperature

Water temperature is one of the most important environmental factors affecting all forms of aquatic life in rivers and streams (Annear *et al.* 2004). Temperature is especially important for Atlantic salmon given that they are poikilothermic (*i.e.* their body temperatures and metabolic processes are determined by temperature). Temperature can be a stimulant for salmon migration, spawning, and feeding (Elson 1969). Temperature can also significantly influence egg incubation success or failure, food requirements and digestive rates, growth and development rates, vulnerability to disease and predation, and may be responsible for direct mortality (Garside 1973; Spence *et al.* 1996; Peterson *et al.* 1977, Whalen *et al.* 1999b).

2.4.2 Dissolved oxygen

All lifestages of Atlantic salmon require high levels of dissolved oxygen (DO) for proper growth, development, and survival (Spence *et al.* 1996). Dissolved oxygen enters the water through direct diffusion from the atmosphere, and through photosynthetic processes occurring in aquatic macrophytes and phytoplankton. Oxygen absorption from the atmosphere increases in turbulent waters. Turbulent water can also decrease temperature which inherently increases oxygen carrying capacity. Oxygen content in aquatic ecosystems typically declines at night due to decreased photosynthetic activity (Fact Sheet FA27). The numeric value of saturation depends on a combination of water temperature, elevation, and barometric pressure, though an approximate range for DO saturation at sea level when temperatures are between 33 and 45°F is 11 – 14 mg/L. (Mortimer 1956).

2.4.3 Nutrients

A stream's productivity partly determines the health, fitness, and survival of species that reside in it, as well as the overall biomass of fish produced. Productivity is dictated by nutrient quantity and availability. Nutrient inputs into coastal watersheds can be either organic or inorganic in form. Inorganic nutrient inputs are generally a result of bedrock weathering; are typically found in the ionic state; and may include elements such as calcium, magnesium, and potassium (Fernandez *et al.* 2003). The three inorganic nutrients that are considered essential for growth and reproduction of all living matter are carbon (C), nitrogen (N), and phosphorus (P) (Stockner and Ashley 2003). Both carbon and nitrogen are ubiquitous in their gas phase whereas phosphorus is not (Stockner and Ashley 2003).

Phosphorus is naturally available as either inorganic phosphorus, originating from the slow erosion of bedrock material, or organic phosphorus which comes from plant and animal matter. Phosphorus is extremely immobile in soils and is quickly adsorbed to soil particles forming compounds with elements such as iron (Fe), aluminum (Al) and calcium (Ca) (Armstrong *et al.* 1999). As a result, phosphorus is often a limiting nutrient for aquatic plant and algae growth (Armstrong *et al.* 1999). Reduced phosphorus availability can limit overall productivity, species composition, and potentially ecosystem function in both aquatic and riparian vegetation communities. The composition of riparian vegetation largely determines light intensity levels that reach a stream as well as the rate and volume in which sediment and organic material is disseminated throughout the stream (Murphy and Meehan 1991).

Organic nutrient inputs into streams and rivers are often of allochthonous origin. Dissolved organic matter (DOM) constitutes a large proportion of the organic carbon in all aquatic ecosystems and is often a significant carbon resource for heterotrophic microorganisms (Findlay and Sinsabaugh 1999). Diverse sources, compositional complexity and multiple transformation pathways have made it difficult to generalize about the bioavailability of this material (Findlay and Sinsabaugh 1999). Recently, there has been dramatic progress in identifying sources of DOM, describing its composition and tracing its movement through microbial food webs (Findlay and Sinsabaugh 1999).

2.4.4 pH

Both chronic and episodically acidified freshwater environments can have numerous negative impacts on all life stages of Atlantic salmon. The pH of a watershed is primarily influenced by three solutes; the H⁺ ion, dissolved organic acids, and dissolved metals (principally Al and Fe), all of which are interrelated (Peterson *et al.* 1989). The abundance of the H⁺ ion directly influences pH. Increases in dissolved organic acids also have the ability to drive down the pH, however suppression of pH by organic acids can simultaneously reduce the toxic effects of many dissolved metals at low pH through complexation of metals by these organic ligands (Baker and Schofield 1980; Driscoll *et al.* 1980).

Numerous studies have shown that declines in pH are capable of impairing the development of juvenile Atlantic salmon (Staurnes *et al.* 1995; Brodeur *et al.* 2001). Low pH, particularly levels below 6.0, impairs the seawater tolerance of Atlantic salmon smolts (Staurnes *et al.* 1993; Staurnes *et al.* 1996; Kroglund and Staurnes 1999). When combined with increased metal ions such as aluminum, low pH has been shown to produce a synergistic negative effect, dramatically reducing the seawater tolerance of salmon smolts beyond that of just low pH (Staurnes *et al.* 1993). In addition to reducing osmoregulatory abilities, this combination of low pH and high aluminum may also cause significant swelling and fusion of secondary lamellae in gills of Atlantic salmon (Smith and Haines 1995) and, at times, up to 100% mortality of smolts (Kroglund and Staurnes 1999). Sensitivity to the pH/ aluminum interaction increases as smolting progresses (Staurnes *et al.* 1993) and exposure to these conditions may impair physiological functions in just a few hours, leading to a reduction in seawater readiness and overall survival of migrating Atlantic salmon smolts (Staurnes *et al.* 1996).

2.4.5 Dissolved organic carbon

Dissolved organic carbon (DOC) plays myriad roles in aquatic ecosystems. DOC can be both beneficial and harmful to aquatic life (Figure 2.4.5). DOC can function as both an acid and a base (Kullberg *et al.* 1993), however, DOC is typically acidic and therefore it can be expected that as levels of DOC increase, pH will decrease. The amount of DOC present in a watershed can be influenced by rainfall, temperature, runoff rates and atmospheric conditions; all of which have an influence on the generation of organic matter. DOC is a byproduct of decomposing natural organic matter and composed of humic substances. These humic substances can serve as a food source for filter feeders as well as chelating agents that often bind to toxic agents, such as aluminum, and forms relatively non-toxic organic complexes (Kullberg *et al.* 1993; Kramer, 1986).

Aluminum, the third most abundant element in the earth's crust, in high concentrations is recognized as highly toxic to aquatic organisms (Rosseland *et al.* 1990). Aluminum toxicity is heavily influenced by the levels of dissolved organic matter in a system. At pH 4.5 both DOC and aluminum are independently toxic to some organisms, yet together they act antagonistically, each reducing the toxic effect of the other (Kullberg *et al.* 1993). Humic substances are also known to bind with phosphorous (Thurman 1985) and form organic complexes with calcium that can decrease their availability to organisms (Kullberg *et al.* 1993). In some cases, DOC can itself become toxic to organisms

(Kullberg *et al.* 1993). In acid streams in Sweden (pH<5.7), species richness was reduced in low colored streams but increased with increased color up to 300 mg Pt L-1. At a color greater than 300 mg PT L-1 the higher humic material concentrations became toxic, thereby reducing species richness (Kullberg *et al.* 1993). In regards to Atlantic salmon, moderate levels of DOC appear to provide a buffer against toxic aluminum in some eastern Maine rivers (Liebich *et al.* unpublished data 2007).

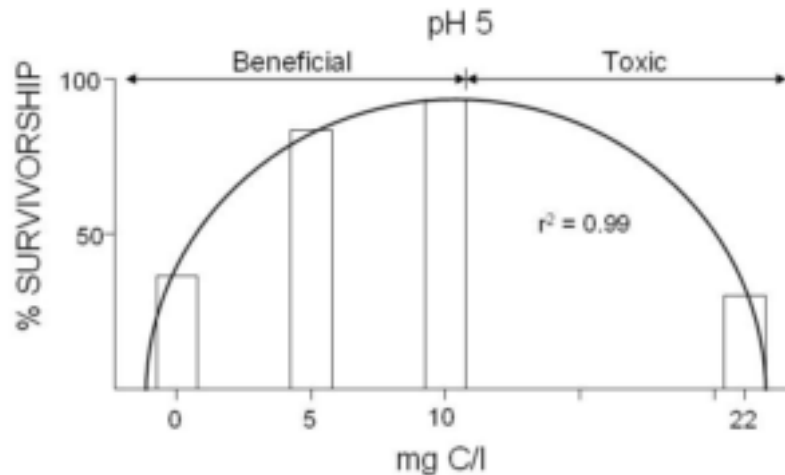


Figure 2.4.5. The response in percent survivorship of *Daphnia magna* (L.) to increasing concentrations of humic material (recreated from Kullberg *et al.* 1993)

2.5 Connectivity

Connectivity of a river system refers to the flow, exchange, and pathways that move organisms, energy, and matter through these systems. The interrelated components of watershed, hydrology, geomorphology, biology, and water quality, together with climate, determine the flow and distribution of energy and material in river ecosystems (Annear *et al.* 2004). River corridors are linear systems, at least in part, in which a gradient of physical, chemical, and biological change occurs from source to mouth (Annear *et al.* 2004). The river continuum concept (RCC; Vannote *et al.* 1980) describes watershed processes as being a network of physical gradients and associated biotic adjustments as the river flows from its headwaters to the mouth (Figure 2.5). As a stream flows from its headwaters downstream, channel width, discharge and sediment load increases and the direct influences of the riparian area weakens as the influx of organic material from upstream sources begins to dominate and the canopy no longer plays a significant role in regulating light inputs. Disruption of the physical and hydrologic connectivity will change the biological structure (Vannote *et al.* 1980). River and stream continuity is a critical component to energy transport within a watershed (Elwood *et al.* 1983) influencing the availability and types of food sources for juvenile salmon as well as the behavioral mechanism in which food sources are obtained. Nutrients, in the form of organic matter, are transported throughout a watershed via a network of biotic and abiotic interactions. Flow and channel form control the rate in which nutrients and organic matter is transported downstream (Annear *et al.* 2004), whereas macroinvertebrates and microbial action are critical to the retention and nutrient cycling of organic material.

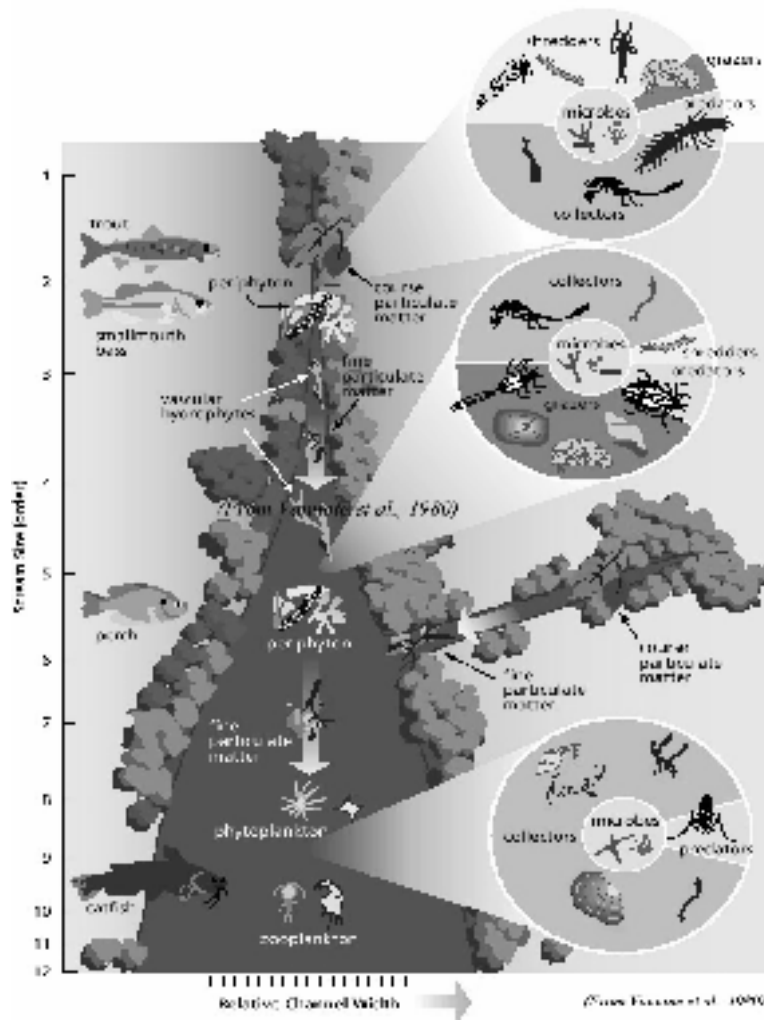


Figure 2.5. The river continuum concept reveals the shift in biological function in relation to corresponding energy inputs from upstream to downstream

2.5.1 Nutrient cycling and transport

The flow of water off of the surrounding landscape is needed to mobilize and transport nutrients and sediments throughout the watershed, which in turn supports the streams biotic communities and shapes the physical habitat. Nutrient inputs into coastal watersheds are derived from atmospheric, terrestrial, and marine sources. Atmospheric deposition of nutrients likely occurs at trivial levels so the focus will be on terrestrial and marine sources.

Terrestrial nutrients

Both organic and inorganic nutrient inputs are vital to proper ecosystem function. Organic inputs into a river system are typically derived from riparian habitats. Therefore, headwater streams primarily obtain energy sources from riparian zones in the form of large woody debris, leaves, and needles (Murphy and Meehan 1991). In contrast, larger rivers receive their primary energy inputs from the finer particulate matter as a product of the material drift from headwater streams (Murphy and Meehan 1991).

Marine derived nutrients

In rivers and streams with diadromous fish, migratory behaviors serve as a bi-directional conduit for transporting nutrients into and out of riverine ecosystems. Therefore, diadromous fish communities can play an indispensable role in the transport of nutrients between the freshwater and marine environment. During spawning migrations the seasonal influx of anadromous fish into coastal watersheds may serve as a critical source of nutrients in the form of marine derived nutrients (MDNs). MDNs are transported into inland waters and deposited through gametes, feces, urea, and carcass decay (Saunders *et al.* 2006). Once deposited, MDNs are utilized through microbial and aquatic insect consumption as well as by other fish, terrestrial predators, and opportunistic feeders. In the northeast, Atlantic salmon represent one species among a host of diadromous fish species that have long been part of the region's coastal river ecosystems. Due to the reportedly high historical abundances of diadromous fish communities in Maine, it is likely that MDNs provided several important ecological functions for coastal river systems. Ecological functions may have included habitat conditioning, predator buffering, increase in prey abundance, and increase stream productivity through the deposition of these MDNs (Fay *et al.* 2006; Saunders *et al.*, 2006).

2.5.2 Biotic interactions

The biological communities, energy and material resources, and physical habitat within a stream ecosystem largely determine the flow of energy through that system (Murphy and Meehan 1991) and ultimately govern where and how salmon fit into the ecological community. Biotic interactions in aquatic ecosystems are highly complex and involve predators, competitors, and prey, as well as an exchange of parasites and diseases between host organisms (Spence *et al.* 1996). Atlantic salmon play a role in one or all of these niches during each stage of their freshwater, estuarine, and marine lifecycles.

Atlantic salmon as predators

As predators, Atlantic salmon rely on the energy-flow processes operating at multiple trophic levels throughout their life cycle. A diversity of forage including numerous species of fishes, plankton, and both aquatic and terrestrial invertebrates is needed to sustain the many life stages of Atlantic salmon. Prey availability does not appear to be a limiting factor later in the salmon's life cycle, possibly due to the opportunistic nature of salmon predation (Reddin 1985; Jacobsen and Hansen 2001; Kallio-Nyberg *et al.* 2004; Lacroix and Knox 2005). Although there is abundant evidence that Atlantic salmon are opportunistic feeders (Levings 1994; Shelton *et al.* 1997; Hansen and Pethon 1985; Reddin 1988; Hislop and Shelton 1993; Sturlaugsson 1994), there is also a large amount of evidence from stomach samples, plankton samples, and trawling, that salmon may utilize selective feeding when possible (Hansen and Pethon 1985; Jacobsen and Hansen 2000; Andreassen *et al.* 2001; Holst *et al.* 1996). Regardless of whether Atlantic salmon exhibit opportunistic or selective feeding behavior, it is not disputed that salmon do show signs of a gradual change in diet as they move from freshwater to the open ocean.

In freshwater, juvenile salmon feed opportunistically on all major types of invertebrates in the drift and select for larger prey as they increase in size. Keeley and Grant (1997)

found that in Catamaran Brook, New Brunswick, juvenile salmon will consume all major types of invertebrates except for water mites (Hydracarina). They also found that newly emerged salmon typically feed on smaller prey than the average available in the drift while juvenile salmon larger than 4.6 cm feed on prey larger than average available in the drift. Stomach samples of juvenile Atlantic salmon have included Chironomidae, Diptera, Hydracarina, Ephemeroptera, Simuliidae, Trichoptera, Coleoptera, and Ostracoda (Keeley and Grant 1997).

As salmon pass through the estuarine environment during their transition from freshwater to marine life stages, slight changes in prey availability and selection occur. The abundance and availability of prey in the estuary is important for salmon survival during this transition into the marine environment (Andreassen *et al.* 2001; Hansen *et al.* 2003; Kallio-Nyberg *et al.* 1999). The food web in the upper estuary area is based on detritus, invertebrate and organism drift supplied by the river (Levings 1994; Rikardsen *et al.* 2004). Andreassen *et al.* (2001) found that post-smolts in the estuary preferred intertidal gammarid amphipods.

In the marine environment, Atlantic salmon begin to exhibit more dramatic changes in diet. There are distinct differences in prey between coastal and oceanic waters (Levings 1994; Hansen and Pethon 1985) and there are also marked differences between prey in the northeast and northwest Atlantic. Fish are found more frequently as prey items in the northwest while crustaceans are more frequently found in the northeast (Levings 1994; Hansen and Pethon 1985). Different ages and size classes of salmon have been found to prefer different prey items (Jacobsen and Hansen 2001). Sturlaugsson (1994; 2000) found that the most important prey of post-smolts in coastal water off of Iceland were decapods (crab larvae), amphipods, copepods, dipterans, euphausiids and fish larvae. Post-smolts in the Gulf of St. Lawrence preferred invertebrates (Chironomidae) and crustaceans (Gammaridae) early in the summer, and small fish and euphausiid crustaceans later in the summer/fall (Dutil and Coutu 1988). Offshore food webs are often based on picto-plankton (Levings 1994). In the offshore environment prey is dominated by crustaceans and fish, with the most common being 0-age pelagic fish such as sand lance and capelin (Templeman 1968; Lear 1980; Reddin 1985; Dutil and Coutu 1988; Reddin and Short 1991; Holst *et al.* 1996; Shelton *et al.* 1997; Andreassen *et al.* 2001). In the oceanic areas of the Norwegian sea, the most common prey of post-smolts were hyperrid amphipods, euphausiids, 0-age group herring and redfish larvae (Holst *et al.* 1996). Important fall foods in the northeast Atlantic are hyperrid amphipods, euphausiids and mesopelagic shrimp. During winter, important food includes various mesopelagic fish such as lantern fish, pearlsides and barracudinas (Jacobsen and Hansen 2001).

During homeward migration, Atlantic salmon feeding ceases or is greatly reduced. Salmon that do exhibit feeding behavior during homeward migration have been found to primarily consume fishes such as herring, sprat, and sand eels (Fraser 1987). Of the salmon that do continue feeding during homeward migration, most appear to feed until a certain point in early June or July when they enter their home estuary, at which point feeding ceases (Lear 1972).

Atlantic salmon as competitors

As competitors, Atlantic salmon may play a vital role in overall ecosystem function. All life stages of Atlantic salmon interact with species around them. The presence or absence of native and non-native species can significantly affect behavior, performance, and survival of Atlantic salmon. In the freshwater environment Atlantic salmon interact with a more finite set of competitors, whereas in the estuarine and marine environments much less is known about the overall function of the food webs in which Atlantic salmon are present.

In freshwater, prior to European colonization, Maine Atlantic salmon co-existed with 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*), were common in freshwater habitats occupied by Atlantic salmon (Saunders *et al.* 2006). 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 (Fay *et al.* 2006).

Atlantic salmon as prey

Atlantic salmon are preyed upon by a host of avian, terrestrial, and aquatic predators. Predation can occur in the freshwater as well as the estuarine and marine environments. In freshwater, predators can include a variety of native species (e.g. herons, mergansers, kingfishers, burbot, eels, brook trout, otters and mink; Anthony 1994) and a variety of introduced non-native species including small mouth bass, large mouth bass, chain pickerel, brown trout, splake, and more recently, northern pike. Native to all the major drainages within the DPS, brook trout and American eel are likely the two most important piscine predators of Atlantic salmon (Fay *et al.* 2006). Elson (1941) and Godfrey (1957) reported that Atlantic salmon fry and parr are preyed upon significantly by American eel.

As Atlantic salmon pass through the estuary they experience high levels of predation. Hatchery-reared and wild fish are both preyed upon in estuaries, and Hvidsten and Lund (1988) found no difference between predation of hatchery-reared and wild salmon smolts in Norwegian estuaries. Mortality may be higher for salmon migrating earlier or later than the “migration window” during which most smolts migrate (Ritter 1989; McCormick *et al.* 1998). Predation rates through the estuary often times result in up to 50% mortality during this transition period between freshwater to the marine environments (Larsson 1985). There is, however, large annual variation in estuarine

mortality which is believed to be dependent upon the abundance and availability of other prey, as well as the spatial and temporal distribution and abundance of predators (Anthony 1994). In addition, the transition from fresh to saltwater may place osmotic stress on juvenile salmon. This increase in osmotic stress in the presence of new marine predators throughout the estuary may impair predator response and increase predation mortality (Jarvi 1989a; 1989b; 1990; Handeland *et al.* 1996; Dieperink *et al.* 2002). One potential adaptation of Atlantic salmon to avoid estuarine predation is migrating at night. Atlantic salmon smolts have been shown to specifically avoid migration at dawn and dusk and have also been shown to move quickly from freshwater to the ocean (Anthony 1994; Ibbotson *et al.* 2006). Predation mortality throughout the estuary has been shown to decrease during periods of high water discharge (Hvidsten and Hansen 1988; Hosmer *et al.* 1979) and hatchery smolts have had higher levels of survival when released closer to the ocean, possibly because of reduced predation threats (Hvidsten and Mokkelgjerd 1987).

Throughout the estuary, predation rates can be quite high and may be a result of numerous predation risks from numerous species including but not limited to Atlantic cod (*Gadus morhua*), double-crested cormorants (*Phalacrocorax auritus*), red-breasted mergansers (*Mergus serrator*), and harbor seals (*Phoca vitulina*; Anthony 2000). Cod are believed to prey on smolts as they have been shown to congregate in estuaries of rivers in both the U.S. and parts of Europe during smolt migration (Hvidsten and Mokkelgjerd 1987; Hvidsten and Lund 1988; Anthony 2000). Cod predation in the river Surna, Norway is believed to be a significant component of high mortality where smolt mortality in sympatric reaches has been documented to be as high as 24.8% (Hvidsten and Mokkelgjerd 1987). In addition to piscine predators, avian predation is also an important cause of mortality in estuaries (Anthony 1994, 2000; Dieperink *et al.* 2002, Meister and Gramlich 1967). Cormorant predation occurs mainly in estuaries (Anthony 1994, 2000) and some research has shown that it can have a significant impact on salmon stocks (Meister and Gramlich 1967; Kennedy and Greer 1988). Anthony (2000) indicates, however, that cormorant predation is limited in time and space and occurs only when smolts are running. Marine mammals, specifically pinnipeds also prey upon Atlantic salmon in estuaries. Carter *et al.* (2001) found that harbor seal predation on salmonids in two Scottish estuaries was seasonal, whereas Anthony (1994, 2000) suggests that pinnipeds and other marine mammals are major contributors to Atlantic salmon mortality.

Many salmon are also lost to predation during their first weeks at sea (Jonsson and Jonsson 2004a), although it is difficult to document predation and natural mortality of salmon at sea (Hislop and Shelton 1993; Friedland 1998; Middlemass *et al.* 2003). In coastal and marine areas, salmon post-smolts face predation threats from piscine, avian and mammalian predators. European post-smolts tend to use the open ocean for a nursery zone, while North American post-smolts appear to have a more inshore distribution, which may expose North American salmon to more mammalian and avian predators utilizing coastal haul-outs and rookeries (Friedland *et al.* 2003a).

Although adult salmon become too large for most avian predators (Anthony 1994), Northern gannets have exhibited the most significant predation on marine-phase Atlantic

salmon to date (Montevecchi *et al.* 2002, Montevecchi and Cairns 2002b). Migrating Atlantic salmon post-smolts pass through several gannet breeding colonies and feeding grounds in the North Atlantic, and are used by gannets to feed their young during the summer (Montevecchi and Cairns 2002b).

Diseases and Parasites

Atlantic salmon are susceptible to a number of viral, bacterial and fungal disease and parasites. Although diseases are often considered to have a negative effect, they are a natural component to a functioning ecosystem and may provide important selection pressures on affected populations. Atlantic salmon are known to be susceptible to furunculosis, infectious salmon anemia (ISA), and sea lice. Disease epizootics are uncommon in New England wild salmon, and furunculosis is the only documented source of mortality in wild salmon (Bakke and Harris 1998; Secombes 1991; Bley 1987). ISA is a contagious and untreatable viral disease that affects a fish's kidneys and circulatory system with mortality rates reaching 80% in hatchery populations (Jarp and Karlsen 1997). ISA is transmitted from infected salmonid sources to clean sites/individuals through sea water. Although sea lice have not been shown to cause direct mortality of wild salmon, low levels of sea lice infestations may cause stress and increase rates of secondary infection in Atlantic salmon (Nolan *et al.* 1999).

Section 3: Ecological disturbances

Alterations in biological communities, physical habitat, energy, and material resources can change a salmon's ecological niche as well as how Atlantic salmon function within that niche. Riverine ecosystems inhabited by Atlantic salmon are highly dynamic systems in which abiotic and biotic components are constantly changing in response to both natural and anthropogenic disturbances. In the riverine ecosystem, disturbance has been defined by Resh *et al.* (1988) as "any relatively discrete event in time that is characterized by the frequency or intensity of events that are outside of the predictable range and that disrupt ecosystems, communities, or population structure, or that changes resources, availability of substratum, or the physical environment". Numerous anthropogenic activities can have effects on all five of the riverine components: hydrology, geomorphology, biology, water quality, and connectivity. The impact that a disturbance has on a river or stream is considerably variable given the hydrodynamics and geomorphology of the system. For example, a rainfall event in a high gradient stream can significantly alter channel morphology through erosion, substrate scouring, and slope failure. In turn, these alterations can result in significant adjustments of stream biota. Conversely, this same rainfall event in a large lowland river may have little channel forming capacity but could result in significant nutrient mobilization between the river and the flood plain; a process which can be highly beneficial to aquatic biota (Resh *et al.* 1988).

Several attempts including the equilibrium model, intermediate disturbance hypothesis, and dynamic equilibrium theory have been developed to explain ecosystem level responses to disturbance. The equilibrium model assumes a relatively constant environment in which communities are a product of competitive, mutualistic, and trophic interactions among species. The intermediate disturbance hypothesis suggests that a competitive hierarchy of species exists and that in the absence of disturbance, resident competitors will prevail and therefore reduce species richness. However, if disturbances are too frequent or too intense, resident competitors will be eliminated, and colonizing species will prevail. The dynamic equilibrium model suggests that community structure is a function of growth rates, competitive exclusion, and frequency of population reductions. In essence, the dynamic equilibrium model suggests that any change in the frequency or severity of disturbances can influence the outcome of species interactions more so than inter-species competition. Resh *et al.* (1988) reviewed the equilibrium model, intermediate disturbance hypothesis, and dynamic equilibrium theory to examine the effects of disturbance on lotic communities. They found that of these theories, the dynamic equilibrium theory may be more representative of lentic environments, such as lakes and ponds, which are less vulnerable to disturbance than lotic environments such as rivers and streams. Whereas, the dynamic equilibrium theory and intermediate disturbance hypothesis best represent the role of disturbance in regulating stream communities.

Although disturbances can be highly variable, and may result in considerable changes to species abundance, diversity, and richness (McElravy *et al.* 1989), they are a natural part of riverine ecosystems, and native species have become well adapted over time to the

disturbances to which they have been routinely exposed. As a result, dramatic changes in natural disturbance regimes may lead to larger population or ecosystem level effects. For example, large increases in stream discharge rates can cause increases in bed load movements that may result in considerable reductions in macro-benthos and algae from large stream sections (McElravy *et al.* 1989), thereby potentially affecting multiple trophic levels. In response to alterations in disturbance regimes, species with short life cycles, such as chironomidae, often re-colonize quite quickly, whereas species with longer life cycles may take considerably longer to re-colonize the disturbed area (McElravy *et al.* 1989). However, even after a disturbance occurs, re-colonization will ensue. The ability of species to re-colonize is a result of evolutionary processes which have enabled species to adapt to disturbances to which they have been exposed. When a new disturbance regime begins (e.g., elevated siltation due to logging) to which there has been no prior exposure, there is no evolutionary basis from which a species can respond; therefore, the ability to re-colonize is diminished (Resh *et al.* 1988). Depending on the life cycle of the species present in disturbed areas, alterations in natural disturbance regimes may have long lasting ecological impacts to riverine ecosystems.

3.1 Changes in hydrology

Stream-flow influences the quantity and quality of habitat available for spawning and rearing. Stream-flow also plays an important role in governing migratory behavior of both emigrating smolts and immigrating adults. Water extractions and discharges for irrigation and commercial purposes may reduce or expose salmon habitat by altering river velocity, volume, depth and temperature. Alternatively, certain forestry and agricultural practices may alter river velocity, volume, depth, and temperature by increasing average flow rates. Stream discontinuity, often associated with the construction of natural or manmade barriers, can also alter flow regimes, water temperature, turbidity, the quality and quantity of food availability in a river system and ultimately displace aquatic communities along the river continuum (Annear *et al.* 2004). The biotic constituents of most riverine ecosystems are adapted to natural changes in hydrology. Species communities function in a state of dynamic equilibrium where some species do well in wet years and other species do well in dry years. For this reason, providing a single flow value cannot simultaneously meet the requirements for all species (Annear *et al.* 2004) or sustain natural ecosystem processes.

Increased runoff caused by clearing of riparian vegetation can alter seasonal stream-flow patterns by increasing high flows and flooding during wet seasons (Hornbeck *et al.* 1970). Recent reviews, however, show that vegetation must be removed from more than 25% of the watershed to produce a significant increase in stream-flow (NRC 2003). Reduced infiltration and the rapid removal of runoff can also lower the water table and cause lower summer base flows and increased water temperature (Spence *et al.* 1996).

Activities that reduce stream-flow have the potential to reduce or expose salmon habitat (Fay *et al.* 2006). Low flows or river draw-downs from irrigation can constrain the amount of habitat available for juvenile rearing; can limit available spawning habitat or expose redds; can delay or influence migratory behavior of smolts and adults. When high flows are reduced: (1) associated wetlands are no longer maintained; (2) local water

tables are not recharged; (3) stream bar and channel areas no longer become inundated and scoured; (4) sediment collects on bars and channel edges and forms lower, narrower stream banks; (5) side channels and backwater areas become disconnected from the main channel or abandoned by the mainstream as they fill in; (6) tributary channel confluences with main stems aggrade locally and push out into the main channel; and (7) the ratio of pools to riffles is significantly altered (Morisawa 1968; Platts 1979; Leopold and Emmett 1983; Hill *et al.* 1991)

Stream flows can be particularly important during the winter and can restrict space needed for overwintering salmonids (Cunjak *et al.* 1988; Elliott *et al.* 1998). Low winter flows can reduce percolation of water through the redd reducing the delivery of oxygen to the eggs (Chadwick 1982). Low winter flows accompanied by ice can threaten redds and juvenile rearing (Elliott *et al.* 1998), and often times result in stranding and suffocation of fry, as well as increased risk of freezing and predation (Cunjak 1996). Cunjak *et al.* (1998) found that juvenile Atlantic salmon abundance in Catamaran Brook, New Brunswick was highest following winters with high stream flow. He also found that egg to fry survival was highest during high winter flows. He further noted that, although all juvenile life stages experienced reduce survival during low flow winters, egg survival was exceptionally low, suggesting that an egg's immobility makes it especially vulnerable to changing ice conditions during low flow periods. Chadwick (1982) conducted a stock recruitment study on a small brook in Newfoundland and found that there was lower survival from egg to fry during low flow, cold winters. Survival was especially low when flows were high in the fall during spawning and low in the winter, believing that eggs became vulnerable to exposure and freezing. Groundwater discharge may serve as winter refugia from ice and variable flow conditions in the winter (Cunjak 1996). Cunjak (1996) reported that numerous species including brown trout (*Salmo trutta*), brook trout (*Salvelinus fontinalis*), various cyprinids, coho salmon (*Oncorhynchus kisutch*), arctic char (*Salvelinus alpinus*), grayling (*Thymallus arcticus*), rainbow trout and juvenile steelhead (*Oncorhynchus mykiss*), and chinook salmon (*Oncorhynchus tshawytscha*) have all been documented utilizing groundwater springs as winter refugia.

3.2 Changes in geomorphology

Stream channels are dynamic systems that are products of the geographical, geological and climatic conditions in which they reside. Channel morphology dictates the presence and distribution of physical features as well as the quantity and quality of habitat available in the stream to salmonids and other biotic communities. Habitat quality is largely a product of stream channel changes that occur from disturbances that are responsible for sediment inputs and redistribution as well as inputs of organic material and large woody debris. Changes in channel morphology may significantly influence the overall abundance and diversity of habitat niches available to various life stages of Atlantic salmon.

3.2.1 Physical habitat

Large woody debris and boulders

Changes in the abundance of large woody debris (LWD) and boulders can have significant impacts on both the physical and biological components of a river system. Boulders and LWD create streambed diversity that provides staging areas for feeding, and protection from climatic events as localized associated backwaters create pools that serve as shelter from extreme temperatures and high flows. Removal of LWD can decrease channel stability as well as decrease the quantity and quality of pools and cover (Hicks *et al.* 1991). Nislow *et al.* (1999) found that LWD placement increased the availability of microhabitats in a small stream in Vermont and subsequently correlated to an increase in Atlantic salmon fry survival. Degerman *et al.* (2004) found that in forested streams of Sweden, brown trout size and densities increased with increasing amounts of LWD. A study conducted by Cederholm *et al.* (1997) in a Pacific Northwest stream, found that after increasing LWD abundance by 7.9 times, there was a significant increase in pool surface area; a significant increase in juvenile coho winter populations; as well as a significant increase in coho smolt yield. Though coho are considered to favor pools more so than Atlantic salmon, juvenile Atlantic salmon are believed to utilize pools and LWD for refuge as they get older, particularly during the winter (Cunjak *et al.* 1998).

Sedimentation

Erosion is a natural and significant source of sediment and nutrients to a system. Stream banks are naturally subject to erosion and even mass wasting, which, when occurring during natural processes, are most often in dynamic equilibrium with stream bank rebuilding process (Platts 1991; Waters 1995). However, when sediment load exceeds transport capacity associated with increases in erosion or alterations of physical habitat features, sedimentation can fill interstitial spaces in gravel that can limit spawning success and reduce available habitat and water quality for juvenile rearing.

Sediments are considered a major pollutant in U.S. waters (Waters 1995; U.S. Environmental Protection Agency 2000). The U.S. Environmental Protection Agency (2000) identified bacteria, siltation, nutrients, and metals (primarily mercury) as the leading cause of water quality impairment in the U.S.. Agriculture, forestry, mining and development and other activities that can expose soils or remove riparian vegetation can increase the rate in which sediments and nutrients enter a stream (Chamberlin *et al.* 1991; Nelson *et al.* 1991; Platts 1991; U.S. Environmental Protection Agency 2000).

When transport capacity exceeds sediment load, the stream channel will make either vertical adjustments or enlarge laterally (Annear 2004). Wide and shallow channels are more susceptible to rapid temperature fluctuations (Cunjak *et al.* 1998); are more prone to extreme temperatures; can be an impediment to migration under some conditions; can limit availability of cover; and may limit the quantity of Atlantic salmon spawning and rearing habitat. Many river reaches in Maine are currently considered to be wide and shallow (NMFS and USFWS 2004). The natural bedrock geology of Maine's rivers and streams are indicative of systems that may have always had high width to depth ratios, so these conditions may be natural to an extent (Fay *et al.* 2006). But the history of extensive logging and log drives in and around Maine rivers suggests that the impacts of log drives may have contributed, in part, to current habitat conditions.

If siltation rates exceed transport capacity of the stream then fine sediment deposition can fill interstitial spaces in the redd preventing through-flow of highly oxygenated water to developing embryos or sac fry (Waters 1995); can have an armoring effect that can entrap emerging fry (Waters 1995); can reduce invertebrate abundance and diversity (Nelson *et al.* 1991; Waters 1995); and can disrupt feeding and social behavior of juvenile salmon (Bisson and Bilby 1982; Sigler *et al.* 1984). High turbidity can also modify light penetration. Over time, reduced light penetration can reduce photosynthesis, which can result in decreased release of oxygen into the water (Waters 1995). Additionally, turbid environments can cause shallow lakes, ponds, bays and dead-waters to fill in faster potentially smothering benthic habitats.

Waters (1995) reports on several studies that document direct mortality of juvenile salmonids, including rainbow trout, coho salmon, and steelhead trout, when exposed to suspended sediment concentrations between 500 and 1500 mg/l. Cunjak (1988) conducted a study in a Nova Scotia river subject to elevated sedimentation from land use activity. He found that 40% of Atlantic salmon parr observed in the winter were located under stones within salmon redds which accounted for only 10% of the total study area. He suggest that the high utilization of redds by parr for over-wintering was likely due to high embeddedness within the stream. Given that the process of digging a redd cleans the gravel, it also increases interstitial spaces within the substrate needed for juvenile over-wintering.

3.3 Changes in riparian zones

Changes in riparian zones may lead to a range of effects on stream ecosystems. Conversion of forested riparian lands to open lands can increase temperature, siltation, and nutrient flux. For example, the removal of the canopy and riparian vegetation decreases stream shading, thereby subjecting streams to greater temperature fluctuations. It has been suggested that the effects of canopy removal on stream temperatures may be cumulative and can cause changes in temperatures such that they become progressively warmer as water travels downstream (Murphy and Meehan 1991). Elevated temperatures can subject salmonids to higher predation rates, increased susceptibility to disease and even direct mortality. In addition to increasing stream temperatures, conversion of land-cover from forested to open lands can reduce soil infiltration rates which can cause increased storm flow peaks and decreased base flow (Leopold 1968; Poff *et al.* 1997).

The effects of riparian alterations on salmon populations have the potential to be quite severe. Moring (1975) concluded that the absence of riparian buffers were largely responsible for declines in salmonid populations in Oregon streams along reaches that had been clear cut. Erman and Mahoney (1983) reported that buffers less than 30 meters were insufficient in protecting streams from reduced macroinvertebrate communities.

3.4 Changes in water quality

3.4.1 Temperature

Water temperatures can be influenced by changes in riparian cover, dams, alterations in stream channel morphology (Annear *et al.* 2004), waste water discharge, urban

development, and global climate change. Changes in water temperatures can alter fish communities by giving more tolerant species a competitive advantage, change aquatic plant and algae communities, and alter dissolved oxygen concentrations. Water temperature plays a very important role in the health and survival of Atlantic salmon as water temperature is the principle factor that determines the northern and southern extent of their range. Water temperature influences spawning and spawning success, migration, feeding behavior, predator avoidance and tolerance to disease (Annear *et al.* 2004).

3.4.2 Nutrients and dissolved oxygen

Most aquatic organisms inhabiting a riverine ecosystem require some minimum concentration of dissolved oxygen. When ecological disturbances occur that disrupt (decrease) the natural DO concentrations, aquatic organisms may be at risk of oxygen deprivation potentially causing reduced growth or direct mortality. Numerous activities such as agriculture, forestry, flood control, and other land use practices can have dramatic effects on dissolved oxygen content by influencing nutrient loads. Anthropogenic activities may enhance nutrient loads leading to a eutrophic (nutrient rich) system. Alternatively, similar activities can reduce nutrient availability resulting in an oligotrophic (nutrient poor) environment. Any change in nutrient availability can have severe impacts on aquatic ecosystems.

Eutrophication results from excess nutrients that can increase growth of aquatic algae and cause algal blooms resulting in numerous impacts to multiple processes occurring within aquatic ecosystems. Algal blooms can kill submerged aquatic vegetation (SAV) by blocking sunlight. Large die-offs of algae following blooms also impair aquatic systems as decomposition of dead algae consumes large quantities of oxygen which can result in significant oxygen depletion (NMFS and USFWS 2005). Reduced SAV and dissolved oxygen (DO) can directly harm salmon, and cause indirect harm by affecting prey species and other necessary ecological functions. Alternatively oligotrophication results from the depletion of nutrients from rivers and streams reducing productivity, growth and survival of aquatic organisms. Only recently has oligotrophy been identified as a threat to aquatic ecosystems. In the Pacific North West, oligotrophication has been identified as a significant threat to salmonid ecosystems (Stockner and Ashley 2003). Oligotrophication in many west coast salmon streams is thought to be a result of dam construction, timber harvesting, and wetland loss limits; all of which interfere with natural nutrient cycling regimes. In oligotrophic systems, DO concentrations are typically sufficient to sustain aquatic communities; however oligotrophic environments may have a profound impact on the productivity and biodiversity of aquatic communities (Stockner and Ashley 2003). A decrease in productivity and associated prey availability may result in increased competition for this highly finite resource, potentially resulting in competitive exclusion of species such as Atlantic salmon.

3.4.3 pH

Atlantic salmon life stages differ in their sensitivity to pH. The acidification of surface waters can result in increased mortality, reproductive failure, reduced growth rate, skeletal deformities, and increased uptake of heavy metals in most fish (Haines 1981). As fish mature, they become more resistant to pH, hence adult fish are more resistant to

low pH than any other life stage (Haines 1981). However, pH does cause reproductive failure in Atlantic salmon at pH levels higher than what is acutely toxic to adult fish (Haines 1981).

Declines in pH not only impact fish directly, but can also lead to altered speciation of many metals that occur naturally in small concentrations, and which also occur in most Atlantic salmon streams and rivers. Speciation changes that occur due to low pH can increase the toxicity of certain metals to resident fishes. Reduction in pH is known to increase the toxicity of metals including aluminum, copper and zinc. Aluminum is a highly abundant, naturally occurring element that can be found in numerous forms. Though all aluminum is toxic, the inorganic monomeric (labile) aluminum is most toxic to fish. As pH falls below 6.0 the level of toxicity of aluminum increases (Driscoll *et al.*, 1980; Steve McCormick, personal communication). The toxicity of aluminum is caused when aluminum binds to the gill epithelium resulting in the epithelium becoming more permeable to ions (Exley *et al.* 1991). Both dissolved organic carbon and calcium protect fish from the negative impacts of low pH and elevated aluminum. In addition, dissolved organic carbons can form complexes with aluminum making it less toxic to fish (Driscoll *et al.* 1980). Calcium protects fish from the negative impacts of low pH and elevated aluminum. Thus, when calcium is low the negative impacts of low pH and elevated aluminum are greater (Steve McCormick, personal communication). Short-term laboratory exposure to suboptimum levels of pH, aluminum and calcium (pH 5.8, total aluminum 80 ug/l, calcium 2 mg/l) can block the normal development of salinity tolerance in Atlantic salmon that occurs during the parr-smolt transformation (McCormick, personal communication). This could likely lead to higher mortality of these fish upon seawater entry (McCormick, personal communication).

3.4.4 Dissolved organic carbon

Stream systems in Eastern Maine with high DOC are often associated with peatlands. Peatlands are essentially large sinks of organic carbon which account for one third of the global soil carbon stock (Gorham 1991; Jenkinson *et al.* 1991). Recent studies suggest that these carbon sinks may be destabilizing causing them to release large amounts of excess carbon in either gaseous or aqueous forms (Freeman *et al.* 2001; Worrall *et al.* 2003). Schindler *et al.* (1997) found that in North American streams flowing into boreal lakes DOC concentrations have increased by 30 to 80% over a twenty year period. Similar studies in the United Kingdom have shown a 65% increase in DOC in freshwater draining from upland catchments over 12 years (Reynolds and Fenner 2001). The cause for the increase in DOC may be related to one or a number of factors associated with global climate change. Increase in temperatures can result in increased decomposition rates resulting in excess carbon (Freeman *et al.* 2001; Worrall *et al.* 2003); increase rainfall and associated elevated discharge rates can result in an increase in DOC export (Forsberg 1992); and increased Carbon Dioxide (CO₂) levels increases CO₂ uptake by plants and the excess carbon is either exuded through the air or through the water as organic carbon (Freeman *et al.* 2004). Changes in DOC can influence water chemistry and associated aquatic ecosystems (See section 2.4.5).

3.5 Changes in connectivity

The removal or destruction of habitat features (i.e. sedimentation, removal of riparian buffers, etc); alterations in biotic communities (i.e. introduction of predators, competitors, etc); and barriers to fish passage (i.e. dams, culverts, thermal and pollution barriers, etc.) subsequently translates into a reduction in the amount of space that all life stages of Atlantic salmon can utilize. The impacts to Atlantic salmon associated with reduced space are reflected at both the individual level and at the population level affecting growth and survival, and ultimately reducing overall abundance and productivity.

3.5.1 Nutrient cycling and transport

Terrestrial nutrients

Many salmon streams, particularly in the uplands of larger river systems, are underlain by old, crystalline bedrock, are naturally poor in nutrients, and consequently, have low levels of primary productivity (Elliott *et al.* 1998). For several decades, limnological research has put emphasis on the consequences of excess nutrient inputs from anthropogenic activities; a source of nutrients which is frequently blamed for eutrophication of aquatic ecosystems. Only recently, has oligotrophy been identified as a threat to aquatic ecosystems, and in the Pacific North West has been identified as a significant threat to salmonid ecosystems (Stockner and Ashley 2003). Oligotrophication in many west coast salmon streams is thought to be a result of dam construction, timber harvesting, and wetland loss limits; all of which interfere with natural nutrient cycling regimes; an affect which may have a profound impact on the productivity and biodiversity of aquatic communities (Stockner and Ashley 2003).

Marine derived nutrients

An additional source of oligotrophication can include over fishing and the associated loss of marine derived nutrients. Numerous studies on the west coast of North America (Bilby *et al.* 1996; Heintz *et al.* 2003; Wipfli *et al.* 1998) have shown that Pacific salmon (*Oncorhynchus* spp.) carcasses provide marine-derived nutrient (MDN) inputs essential to maintaining productivity in freshwater systems and rearing habitats. Stockner (1987) estimated that in the Pacific Northwest out-migrating smolts export less than 5% of the total annual total phosphorus load from the drainage while returning adult spawners contribute between 15% and 40% of the total annual phosphorus budget. This net influx of phosphorus by adults serves as a support system to annual autotrophic aquatic and riparian production cycles (Stockner and Ashley 2003). Though few studies have been conducted on the east coast that would draw any parallel connection to the importance of MDN on the west coast (Bilby *et al.* 1996; Heintz *et al.* 2003; Wipfli *et al.* 1998), MDNs have recently been identified as a potentially significant component of salmonid ecosystems in the Northeast (Saunders *et al.* 2006). In addition, Nislow (2004) found that Atlantic salmon populations in the river Bran, Scotland currently experience a net loss of phosphorus in the freshwater environment and therefore should experience net declines in productivity.

3.5.2 Biotic interactions

Anthropogenic disturbances including habitat alterations, species introductions, and climate change can alter the way in which Atlantic salmon interact within the biotic community by changing the competitive balance between species, or by introducing diseases, parasites, and new vectors of transport (Spence *et al.* 1996). Atlantic salmon have evolved in the presence of a host of native resident and diadromous fish species. However, over the past two centuries species composition and community interactions occurring in Atlantic salmon habitat have dramatically changed due to introductions of non-native species. The presences of any non-native species will inherently interfere with ecosystem function and the evolved species interactions and competitive balances. Introduced species may influence native species directly by increasing competition, predation, and disease transmission, or indirectly through increased partitioning of resources.

Changes in predator/prey interactions

Changes in species interactions essentially dictate the species composition of a given ecosystem. Due to competitive balance between species evolving in a shared environment, any changes in species composition (i.e. introductions of non-indigenous fishes) can significantly alter the species composition and could potentially lead to the extirpation of native species from that system. Although little is known about the prevalence of Atlantic salmon as prey, it is assumed that during one or all juvenile life stages, Atlantic salmon may fall victim to predation by numerous native freshwater species as well as many if not all non-indigenous species. Non-indigenous species present in Gulf of Maine Atlantic salmon rivers include smallmouth bass (*Micropterus dolomieu*), largemouth bass (*Micropterus salmoides*), black crappie (*Pomoxis nigromaculatus*), chain pickerel (*Esox niger*), northern pike (*Esox lucius*), white catfish (*Ameiurus catus*), common carp (*Cyprinus carpio*), brown trout (*Salmo trutta*), and rainbow trout (*Onchorhynchus mykiss*). Of greatest concern is the potential for artificially increased freshwater mortality rates that may be occurring as a result of predation of juvenile salmon by non-indigenous species such as smallmouth bass, chain pickerel, and northern pike during juvenile freshwater life stages. Smallmouth bass are particularly important as they can occupy and thrive in riverine habitats that are often selected for by juvenile Atlantic salmon (Fay *et al.* 2006). Recent illegal introductions of northern pike in portions of the Kennebec basin and most recently in Pushaw Lake in the Penobscot basin may become a particularly aggressive predator adding additional predator pressures to juvenile Atlantic salmon, particularly smolts. Brown trout are both an aggressive competitor and predator to Atlantic salmon as they to occupy much of the same habitat features. Brown trout predation is believed to be responsible for the decline of several native salmonid populations throughout the U.S. (Moyle 1976; Sharpe 1962; Alexander 1977; and Taylor *et al.* 1984).

In addition, recent increases in native striped bass populations throughout New England raises concerns of increased smolt mortality during estuarine and seawater migrations. Although striped bass predation on Atlantic salmon has not been quantified, Beland *et al.* (2001) has shown that predation on Atlantic salmon smolts by striped bass can occur. Grout (2006) has also found moderate to strong correlations between striped bass

abundance and salmon return rates in 3 of 4 New England Rivers, but the impact of striped bass predation on salmon has not been thoroughly qualified. There is also some speculation that sharks and skates may eat salmon (Hansen *et al.* 2003).

Marine predation losses of North American stocks may be increasing because of recent increases in avian and mammalian predators from specific coastal rookeries (Montevecchi *et al.* 1988). One avian predator that has shown significant population increases in the past few decades is the Northern Gannets (*Morus bassanus*; Montevecchi *et al.* 2002). Northern Gannets are known to consume Atlantic salmon post-smolts and increases in smolt consumption by Northern Gannets were documented during the 1990's (Montevecchi *et al.* 2002).

Middlemass *et al.* (2003) indicates that there is no evidence that marine mammals are the main causal agents for decline in salmonid abundance, but suggests that they may have substantial effects on local populations in areas where salmonid abundance is already low. Hammil and Stenson (2000) used bioenergetics models to estimate that the total pinniped consumption of salmon in Atlantic Canada rose steadily from 1990 to 1996 whereby in 1996 0.1% of the overall diet of the seals was found to include salmon.

Section 4: Lifestage specific habitat features utilized by Atlantic salmon

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 (Gibson 1993). 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; Egglshaw and Shackley 1985; Gibson 1993; Baum 1997). 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 (Klemetsen *et al.* 2003).

4.1 Adults

Adult Atlantic salmon return to rivers from the sea with the objective of migrating to their natal stream and spawning. Adults ascend the rivers of New England beginning in the spring and will continue their ascent into the fall with the peak influx of adults occurring in June. Although spawning does not occur until late fall, the majority of Atlantic salmon in Maine enter freshwater between May and mid July (Meister 1958; Baum 1997; Dill personal communication). Early migration is an adaptive trait that ensures adults sufficient time to effectively reach spawning areas despite the occurrence of temporarily unfavorable conditions that occur naturally (Bjornn & Reiser, 1991). Salmon that return in early spring spend nearly five months in the river before spawning; often seeking cool water refuge (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). 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 (Baum 1997). Although 2SW adults are the most common, 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 salmon (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 over-winter 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, insuring some level of genetic exchange between generations.

Table 4.1. Life history characteristics of Adult Atlantic salmon in Maine

		USASA C (2004)	Baum (1997)
Size of 2SW fish upon return	Length (cm)		75
	Weight (kg)		4.5
Wild Salmon Returns	Grilse (%)	10	
	2SW (%)	86	
Sex of salmon returns to Maine	Grilse:		
	Male (%)		95 to 98
	2SW & 3SW Female (%)		55 to 75
% Salmon return to sea after spawning			20
% Repeat Spawners 1967 - 2003		3	

4.1.1 Adult freshwater migration

Adult Atlantic salmon returning to their natal rivers or streams require sufficient energy reserves and unobstructed passage to reach their spawning grounds at the proper time for effective spawning (Bjornn & Reiser 1991). Physical and biological barriers can prevent adult salmon from effectively spawning either by preventing access to spawning habitat or impairing a fish's ability to spawn effectively by delaying migration or impairing the health of the fish. The amount of spawning habitat needed for adults is a function of the amount of habitat needed to adequately seed the habitat to maintain sustained populations into the future.

Atlantic salmon may travel as far as 965 kilometers upstream to spawn (EFH Technical Team 1998). During migration, adult salmon require holding and resting areas that provide the necessary cover, temperature, flow, and water quality conditions needed to survive. Holding areas can include areas in rivers and streams, lakes, ponds, and even the ocean (Bjornn and Reiser 1991). Holding areas are necessary below temporary seasonal migration barriers such as those created by flow, temperature, turbidity, and temporary obstructions such as debris jams and beaver dam, and adjacent to spawning areas. Adult salmon can become fatigued when ascending high velocity riffles or falls and require resting areas within and around high velocity waters where they can recover to the point of continuing migration. Holding areas nearby spawning areas are necessary when upstream migration is not delayed and an adult reaches spawning areas before they are ready to spawn.

Table 4.1.1 Adult freshwater migration distance

	EFH Technical Team (1998)
Upper limit of distance traveled to spawn (km)	965

4.1.2 Temperature and oxygen requirements

Adult salmon migratory behaviors are significantly influenced by temperature and dissolved oxygen. Most migratory movement is conducted when temperatures range between 14 – 20°C (Elson 1969). Danie *et al.* (1984) notes that at temperatures above 20°C adult salmon are rarely caught by angling and further states that temperatures between 20°C and 27°C reduces resistance to disease and are therefore indirectly lethal. Shepard (1995) assessed the migratory behaviors of adult Atlantic salmon in the Penobscot River from 1988 through 1992 and found that salmon continued to pass through the fishway at Veazie dam in the lower Penobscot River when temperatures were below 23°C. When temperatures exceeded 23°C, adult Atlantic salmon ceased movement through the fishway until high temperatures abated. Salmon mortalities were associated with daily average temperatures of 26°C to 27°C.

The oxygen requirements of Atlantic salmon are largely dependent upon the activity of the fish and water temperature (Decola 1970). For every 10°C increase in water temperature, an active salmon’s oxygen consumption will generally double (Decola 1970). Kazakov and Khalyapina (1981) studied the oxygen consumption rates of 51 adult Atlantic salmon using a respirometer. At minimal activity, oxygen consumption rates remained stable when oxygen concentrations were depressed to 4.5-5.0 mg/l. At further decreases in oxygen, the fishes breathing function became depressed. When oxygen concentrations reached 2.0 – 2.5 mg/l, fish became excitable and tried to surface. Fish died when oxygen concentrations were reduced to 1.5 – 1.7 mg/l. Decola (1970) states that sustained DO concentrations of 5 mg/l or below would be inadequate for Atlantic salmon and could block migration.

Table 4.1.2 (a). Temperature (°C) requirements of adult Atlantic salmon

	Elson (1969)	Danie <i>et al.</i> (1984)	Shepard (1995)
Migratory range	14 to 20		
Continued Activity			≤23
Reduced Activity		≥20	≥23
Indirect lethal		20 to 27	26 to 27

Table 4.1.2 (b). Behavior of adult Atlantic salmon at varying oxygen levels

		Kazakove & Khalyapina (1981)
Behavior at oxygen levels (mg/l):		
	Stable	4.5 to 5.0
	Excited/Surfacing	2.0 to 2.5
	Death	1.5 to 1.7

4.1.3 Flow and depth requirements

Atlantic salmon can swim at sustained speeds of 2.2 km/hr and a burst speed of 24 km/hr (Elson 1975). Atlantic salmon are rheotactic and require a minimum stream velocity of 0.3 to 0.6 m/sec to stimulate upstream migration (Weaver 1963). In lakes, ponds or deadwaters where flows may fall below the minimum velocities needed to stimulate upstream migration, salmon will enter an active search mode, where salmon actively seek out moving water that would stimulate continued migration. In areas where water velocity exceeds 4.5 km/hr adult salmon require resting areas with a velocity of < 61 cm/s along the way (Haines 1992). Potter (1988) tracked Atlantic salmon in the estuary of the River Fowey, south-west England. He observed that most fish entered freshwater during periods of increased freshwater discharge. Low river flows delayed the migration of salmon into the river, and many fish stayed for several weeks or even months in the estuary before entering fresh-water.

Table 4.1.3. Flow and depth requirements of adult Atlantic salmon during freshwater migration

		Elson (1975)	Weaver (1963)	Haines (1992)
Salmon swim speeds	Sustained (km/hr):	2.2		
	Burst km/hr):	24		
Migratory movements	Minimum Velocity (m/sec)		0.3 to 0.6	
	High Velocity (km/hr)			≥4.5
	Resting (cm/s)			≤61

4.1.4 Diadromous fish interactions

Adult Atlantic salmon interact with other diadromous species both directly and indirectly. Adult migration through the estuary often coincides with the presence of alewives, American shad, blueback herring, and striped bass. The abundance of diadromous species present during adult migration may serve as a prey buffer from seals, porpoises and otters (Saunders *et al.* 2006). As an example, the life history of American shad places pre-spawn adult shad entering rivers and beginning their upstream spawning migration at approximately the same time as early migrating adult salmon (Fay *et al.* 2006). 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 (Fay *et al.* 2006; Saunders *et al.* 1996). In the absence or reduced abundance of these diadromous fish communities, it would be expected that Atlantic salmon will, by default, become increasingly targeted as forage by large predators (Saunders *et al.* 1996).

4.2 Spawning

Water quantity and quality, as well as substrate type and cover are all important for successful Atlantic salmon spawning. Water quantity can determine habitat availability and water quality may influence spawning success. Substrate often determines where spawning occurs and cover can influence survival rates of both adults and newly hatched salmon. Spawning sites are positioned within flowing water allowing for percolation of water through the gravel where up-wellings of groundwater occur (Danie *et al.* 1984). These sites are most often positioned at the head of a riffle, the tail of a pool, or on the upstream edge of a gravel bar where water depth is decreasing and water velocity is increasing (McLaughlin and Knight 1987; White 1942) and where a hydraulic head of water allows for permeation of water through the redd. Redds are most frequently positioned in streambeds where the stream profile is convex (Peterson 1978). A redd constructed on the upstream side of a gravel mound is positioned such that the water is accelerating as it passes over the redd which creates a “force vector” that drives the water downward into the redd (Peterson 1978). The upwelling of water currents and increases in water acceleration are believed to be environmental cues that trigger spawning activity by adults (White 1942; Tautz and Groot 1975).

Once the female Atlantic salmon finds a site, she uses her tail to scour or dig a depression in the gravel, called a redd, where the eggs are deposited. 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. A single female may create several redds before depositing all of her eggs. The digging behavior also serves to clean the substrate of fine sediments that can embed substrate and reduce egg survival (Gibson 1993). 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 & Meister 1971).

4.2.1 Substrate and redd formation

Preferred spawning habitat is a gravel substrate with adequate water circulation to keep the buried eggs well oxygenated (Peterson 1978). Peterson (1978) found in New Brunswick streams that typical spawning substrate consisted of 40- 60% cobble, 22.5-256 mm dia.; 40-50% pebbles, 2.2 – 22.2 mm dia.; 10-15% course sand, 0.5 -2.2 mm dia.; and <3% fine sand, 0.06-0.05mm dia.. Prior to spawning activity, substrate was found to be highly stratified with heavier material near the surface and smaller particles increasing with depth. Following redd excavation, substrate material becomes mixed, however stratification is re-established prior to the eggs hatching the following spring (Peterson 1978). The most productive redds are positioned in habitat consisting of highly permeable course gravel and cobble between 1.2 to 10 cm in diameter (Haines 1992).

Table 4.2.1. Preferred spawning substrate of Atlantic salmon

		Haines (1992)	Peterson (1978)
Cobble:	Diameter (mm)	12-100	22.5-256
	Proportion		40-60%
Pebbles:	Diameter (mm)		2.2-22.2
	Proportion		40-50%
Course Sand	Diameter (mm)		0.5-2.2
	Proportion		10-15%
Fine Sand	Diameter (mm)		0.06-0.05
	Proportion		<3%

4.2.2 Egg pit depth and substrate permeability

Jordan and Beland (1981) found that salmon eggs are buried under 12 - 20 cm of substrate. Jones (1959) found that a 5 kg female can dig a 30 cm pit and bury the pit with a mound of gravel that places the eggs under as much as 60 cm of gravel. The act of digging the pit can serve to clean the substrate of fine sediment (Gibson 1993). Spawning habitat permeability is characterized by the amount of flow through substrate material which is associated with the amount of fine particles in the substrate composition.

Eggs in a redd are entirely dependent upon sub-surface movement of water to provide adequate oxygen for survival and growth (Decola 1970). Water velocity and permeability of substrate allows for adequate transport of well oxygenated water for egg respiration (Wickett 1954) and removal of metabolic waste that may accumulate in the redd during egg development (Decola 1970; Jordan and Beland 1981). Substrate permeability as deep as the egg pit throughout the incubation period is important since eggs are most often deposited at the bottom of the egg pit. Jordan and Beland (1981) found that redds are most frequently constructed in substrate that has a permeability (K_{10})

ranging from 2,500 to 4,680 cm/h at substrate depth of 20 cm and a surface velocity 12 cm above the redd ranging from 49 to 64 cm/sec. Landlocked Atlantic salmon redds, which have similar redd composition to Atlantic salmon, are not successful when permeabilities are less than or equal to 600 cm/h (Peterson 1978). Peterson (1978) reported that typically substrate that contains more than 20% sand (particle size 0.06 to 2.2 mm) has insufficient permeability needed for egg survival. Redds require a minimum velocity greater than 10 cm/sec in order for eggs to hatch (Peterson 1978).

Table 4.2.2. Egg pit depth and permeability of Atlantic salmon redds

		Jones (1959)	Jordan and Beland (1981)	Peterson (1978)
Buried Depth: (cm)		≤60	12 to 20	
Pit Depth: (cm)		30		
Permeability: (cm/h)	Sufficient		2500-4680*	
	Insufficient			≤600

* Permeability was measured at a substrate depth of 20cm, with a surface velocity of 49-64m/sec and a distance above the redd of approximately 12cm

4.2.3 Water depth and velocity

Beland *et al.* (1982) measured water velocity and depth preferences of spawning Atlantic salmon in four rivers in Maine. Female Atlantic salmon constructed redds in water with a mean depth of 38 +/- 0.8 cm and ranging from 17-76 cm in depth. Jones (1959) observed that spawning rarely took place in depths greater than 30 cm. Redds that are constructed in waters too shallow may be at risk of freezing in the winter or the redd may become exposed and the eggs desiccated if the water levels should drop below the top of the redd. Redds that are too deep may not have enough flow to allow for adequate permeation through the substrate.

Jordan and Beland (1981) measured river velocities at 12 cm above the river bottom and found that redds are most frequently constructed in velocities averaging 53 cm/sec with a range of 27 – 83 cm/sec. In most cases velocities < 35cm/sec. and >80cm/sec. were not generally used. Jones (1959) observed that salmon preferred velocities of 31 to 46 cm/sec. and that spawning ceased when velocities were less than 5-8 cm/sec. Water velocities that are too low will not provide adequate oxygenation or cleaning of the eggs and can result in the deposition of fine sediments in the redd; whereas flows that are too high can result in excessive scour causing redd excavation.

Table 4.2.3. Preferred water depth and velocity for Atlantic salmon spawning

		Beland <i>et al.</i> (1982)	Jones (1959)	Jordan and Beland (1981)
Depth:	Mean (cm)	38 ± .08		
	Range (cm)	17-76		
	Preference (cm/sec)	≤30		

Velocity:	Mean (cm/sec)		53*
	Range (cm/sec)		27 - 83*
	Preference (cm/sec)		31 - 46**

* Velocities were measured at 12 cm above the river bottom

** Spawning ceased when velocities were less than 5 - 8 cm/sec

4.2.4 Spawning temperature and timing

Spawning is believed to be triggered by a combination of water temperature and photoperiod. The timing of spawning has likely evolved in response to water temperature (Bjornn and Reiser 1991). Temperature plays a critical role in egg development and is therefore vital in the timing of spawning activity. As such, redd development corresponds with optimal temperature requirements for egg development. Spawning in the Gulf of Maine DPS typically occurs between mid-October through mid-November (Baum 1997) when water temperatures are between 7° to 10°C (Jordan and Beland 1981).

Table 4.2.4. Water temperature and timing of Atlantic salmon Spawning

		Baum (1997)	Jordan and Beland (1981)
Timing:	Month	Mid-Oct. to Mid-Nov.	
Temperature:	C°		7 to 10

4.2.5 pH

As fish mature, they become more resistant to pH, hence adult fish are more resistant to low pH than any other life stage (Haines 1981). However, pH does cause reproductive failure in Atlantic salmon at pH levels higher than what is acutely toxic to adult fish (Haines 1981). Haines (1981) reported apparent reproduction decline and failure for numerous salmonids. Apparent reproductive failure for Atlantic salmon occurred at a pH between 5.0 and 5.5; brook trout, pH 4.5 – 5; and brown trout, pH 4.5 – 5.5. Peterson *et al.* (1980) reported that movement of Atlantic salmon embryos within the egg were reduced at low pH. Beamish (1976) observed that white suckers in acidified lakes did not spawn. Inhibition of spawning was believed to be associated with the females inability to maintain normal serum calcium levels, believed to be related to acid stress. Johnson and Webster (1977) found that brook trout avoided spawning in areas with pH less than 5.

Table 4.2.5 pH at which reproductive failure occurs for various salmonids

		Haines (1981)	Johnson and Webster (1977)
Reproductive Failure:			
	Salmon	5.0 - 5.5	
	Brook Trout	4.5 - 5.0	≤5.0
	Brown Trout	4.5 - 5.5	

4.2.6 Cover

Adult salmon can arrive at spawning grounds several months in advance of spawning activity. Adults that arrive early require holding areas that provide shade, protection from predators, and protection from other environmental variables such as high flows, high temperatures, and sedimentation. Shelter can include pools 1.8-3.6 meters deep (McLaughlin and Knight 1987). Large boulders or rocks, over hanging trees, logs, woody debris, submerged vegetation or undercut banks also provide shade and reduced velocities needed for resting and protection from predators (Giger 1973).

Table 4.2.6. Cover needed by Atlantic salmon during spawning

		McLaughlin and Knight (1987)
Depth:	Pools (m)	1.8 - 3.6

4.2.7 Space

Space plays an important role in Atlantic salmon spawning. A typical Atlantic salmon redd encompasses slightly more than 3.7m² of spawning habitat. The average redd is approximately 2.3m long and 1.5m wide and can be as large as 5.5m long by 6.1m wide (Baum 1997). The number of redds that can be built in a stream is a function of water depth, velocity, and substrate size (Bjornn and Reiser 1991). If adequate space is not available for spawning, or access to spawning areas are impeded, then there is an increased risk of redds becoming super imposed, where a female will dig a redd on top of an existing redd likely resulting in near complete failure of the earlier redd.

The amount of spawning area available to adults should be sufficient to attain sustainability of a watershed. A conservative estimate on the amount of spawners that a stream can accommodate can be made by dividing the area suitable for spawning by four times the average area of a redd (Burner 1951).

Table 4.2.7. Space required for effective spawning by Atlantic salmon

		Baum (1997)
Redd Size:		
Mean:	Length (m)	2.3
	Width (m)	1.5
Maximum:	Length (m)	5.5
	Width (m)	6.1

4.2.8 Fisheries interactions

Sea lampreys are an anadromous fish that ascend rivers in the early spring and spawn in mid June. During their resident time in freshwater, lampreys stop feeding and focus their energy on spawning. Though the spawning activity of lampreys do not coincide with the spawning activity of Atlantic salmon, spawning lampreys likely provide additional

benefits to Atlantic salmon spawning activity in sympatric reaches (Fay *et al.* 2006). In constructing their nests, lamprey carry stones from other locations and deposit them 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 similar in size to 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 for juvenile salmonids (Fay *et al.* 2006).

4.3 Embryo development and larval fry

Embryos develop in the redd for a period of 175 to 195 days (Danie *et al.* 1984). After eggs hatch in late March or April the newly hatched salmon are referred to as larval fry, alevin or sac fry. Alevins remain in the redd for approximately six weeks after hatching and are nourished by their yolk sac (Gustafson-Greenwood and Moring 1991). Alevins emerge from the gravel and begin active feeding in mid-May. At this stage they 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). Survival rates of eggs and larvae is a function of stream gradient, overwinter temperatures, interstitial flow, predation, disease, and competition (Bley and Moring 1988). The fry enter the parr stage within days after emerging from the redd, indicated by vertical bars (parr marks) visible on their sides which act as camouflage (Jones 1959).

Table 4.3. Time needed for Atlantic salmon embryo and larval fry development

		Danie <i>et al.</i> (1984)	Gustafson-Greenwood & Moring (1991)	Gustafson - Marjanen & Dowse (1983)	Jordan & Beland (1981)
Embryo development:	Days	175 - 195			
Alevin Redd Time:	Weeks		6		
Fry Night Emergence:	% at Night			≥95	
Survival from egg to fry:	% survival				15 - 35

4.3.1 Temperature

Spawning occurs on the receding arm of the annual temperature cycle and often occurs near the upper tolerance limit for successful egg incubation. Temperature governs metabolism which in turn increases oxygen consumption (Decola 1970). In contrary an increase in water temperature decreases the amount of oxygen that the water can hold. During the embryonic stage when tissue and organs are developing the demand for oxygen is quite high, and therefore only a narrow range of temperatures can be tolerated. As the fish matures and organs develop, the ability to tolerate warmer temperatures

increases. Decola (1970) describes a temperature range between 0.5°C and 7.2°C as a range of temperatures that apparently does not affect egg mortality; whereas sac fry and eggs exposed to temperatures at or near 10°C experience excessive mortality. Peterson *et al.* (1977) studied the effects of eggs and alevins raised under varied temperature regimes at different points of development. Eggs incubated at less than 4°C immediately after fertilization experienced more than 20% mortality compared to less than 5% mortality when eggs were incubated at temperatures greater than 4°C. In contrary, eggs that eyed at 8°C produced alevins that were progressively smaller the higher the temperature. Peterson *et al.* (1977) described the optimum temperature from fertilization to eye pigmentation as near 6°C.

Table 4.3.1. Temperature requirements for Atlantic salmon embryo and larval fry

		Decola (1970)	Peterson <i>et al.</i> (1977)
Temperature:	Range (C°)	0.5 - 7.2	
	Upper Limit (C°)	10	≥8
	Lower Limit (C°)		≤4
	Lower Limit mortality (%)		20

4.3.2 Dissolved oxygen

Dissolved oxygen is important for proper embryonic development and hatching. Often times, embryos will survive when DO concentrations are below saturation levels but their development is often subnormal either through delayed growth and maturation, performance, or delayed hatching (Doudoroff and Warren 1965). For Atlantic salmon the minimum survival tolerance of embryos ranged from 1.14 mg/L for early development stages; 5.9 mg/L for mature embryos; to 8 mg/L for alevins (McLaughlin and Knight 1987). Decola (1970) states that even though embryos may survive lower DO concentrations, for proper embryonic development DO concentrations should remain at or near saturation with an absolute minimum DO concentration of 7 mg/L within the redd. Depending on the abundance and density of plant and animal communities, including invertebrate densities within the area of the redd, the DO concentration above the stream bed may need to be much greater to sustain a DO of 7 mg/L in the sub-surface water that percolates through the redd (Decola 1970).

Table 4.3.1. Dissolved oxygen requirements of Atlantic salmon embryo and alevin

		Decola (1970)	McLaughlin & Knight (1987)
Minimum Dissolved Oxygen (mg/l):	early embryo		1.14
	mature embryo		5.9
	alevin		8
	Minimum in Redd(mg/l)	7	

4.3.3 pH

Low pH affects fish embryos by corroding epidermal cells, which in turn interferes with respiration and osmoregulation and may delay or prevent hatching (Daye 1981). Peterson *et al.* (1980) conducted four experiments to examine the effects of low pH on salmon egg hatching. Hatching of Atlantic salmon eggs was delayed or prevented if exposed to a static solution of water lowered to a pH of 4.0-5.5 after eye pigmentation had developed. Egg mortalities at pH 6.8, 6.0, 5.5, 5.0, 4.5 and 4.0 were 0, 3, 30, 40, 37 and 97% respectively. Hatching subsequently could be induced in eggs exposed to pH of 4.0 for duration of 10 days or less by returning eggs to a pH of 6.6-6.8. Exposures beyond 10 days resulted in no hatching. Peterson *et al.* (1980) also measured the pH of the Perivitelline fluid within the egg and observed that pH of the perivitelline fell rapidly to near ambient levels within 8 hours after eggs were exposed to low pH. Peterson *et al.* (1980) suggested that the observed effects on hatching were due to inhibition of the hatching enzyme, chorionase.

Table 4.3.2 (a). Point at which pH inhibits hatching of Atlantic salmon eggs

	Peterson <i>et al.</i> (1980)
Hatching delayed or prevented	pH 4.0 - 5.5

Table 3.3.3 (b). Mortality rates for Atlantic salmon eggs exposed to varying pH

	Peterson <i>et al.</i> (1980)					
pH level	4	4.5	5.0	5.5	6.0	6.8
Egg mortality (%)	97	37	40	30	3	0

4.3.4 Metals

Peterson *et al.* (1989) correlated aluminum accumulation in Atlantic salmon alevin tissue to assess alevin mortality when exposed to solutions containing aluminum and dissolved organic anions (both synthetic and natural). Peterson found that both mortality and aluminum accumulation was related to the concentration differences between aluminum and organic anions. A sizable increase in both mortality and body accumulation of aluminum was observed as total aluminum concentrations increasingly exceeded organic anion concentrations. Peterson also noted that the acidic fractions of dissolved organic matter (DOM) are more effective in protecting alevins against aluminum toxicity than are the neutral and basic fractions.

4.3.5 Food

After hatching, larval fry are dependent upon a yolk sac that is attached to their abdomens for nourishment. The yolk sac provides nourishment for larval fry for about six weeks after hatching (Baum 1997). By the time the yolk sac is completely absorbed; the larval fry will be approximately 25 mm in length (Danie *et al.* 1984) and will begin actively foraging on plankton (Baum 1997). At this point the larval fry are termed fry (Danie *et al.* 1984).

Table 4.3.5. Food requirements of larval fry

	Baum (1997)	Danie <i>et al.</i> (1984)
Nourishment time (weeks)	6	
Length upon absorption (cm)		2.5

4.3.6 Emergence and territory development

The period of emergence and the establishment of feeding territories is a critical period in the salmon life cycle since at this time mortality can be very high. When fry leave the redd, they emerge through the interstitial spaces in the gravel to reach the surface. When the interstitial spaces become embedded with fine organic material or fine sand, emergence can be significantly impeded or prevented. Bjornn (1968) found that for three species of Pacific salmon and steelhead trout fry emergence was impeded when the percentage of fine material (particle size 0.64 cm dia.) exceeded 30-40% by volume.

Newly emerged fry prefer shallow (10 - 15 cm deep; Symons and Heland 1978), low velocity (nose velocity of 5 -15 cm/sec and an avg. stream velocity of approximately 31 cm/sec) (Morantz *et al.* 1987) riffle habitat with a substrate consisting of gravel ranging from approximately 2 to 7 cm in diameter (Symons and Heland 1978; Morantz *et al.* 1987). Hedger *et al.* (2005) assessed the physical river habitat variables on the distribution of juvenile Atlantic salmon in the Rivière de la Trinité, Québec, Canada by electro-fishing a range of habitats throughout the length of the river. He reported the optimal stream velocity for fry to be 4 – 4.3 cm/sec. and optimal depth to be 0-5.3 cm. Territories are established by seeking out areas of low velocities that occur in eddies in front of or behind larger particles that are embedded in areas of higher velocities to maximize drift of prey sources (Armstrong *et al.* 2002). Once a territory has been established, fry use a sit-and-wait strategy, feeding opportunistically on invertebrate drift. This strategy enables the fish to minimize energy expenditure while maximizing energy intake (Bachman 1984).

Table 4.3.6. Fry emergence and territory development of Pacific Salmon and Steelhead

	Bjornn (1968)	Hedger <i>et al.</i> (2005)	Morantz <i>et al.</i> (1987)	Symons & Heland (1978)
Impeded: Particle dia. Size (cm)	0.64			
% by volume	30 - 40			
Preference: Water Depth (cm)				10 to 15
Nose Velocity (cm/sec)			5 to 15	
Stream Velocity (cm/sec)			31	
Substrate dia Size (cm)				2 to 7
Optimal: Stream Velocity (cm/sec)		4 – 4.3		
Water Depth (cm)		0 – 5.3		

4.4 Parr

When fry reach approximately 4 cm in length, the young salmon are termed parr (Danie *et al.* 1984). Parr have eight to eleven pigmented vertical bands on their sides that are believed to serve as camouflage (Baum 1997). 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). Most parr remain in the river for two to three years before undergoing smoltification; the process in which parr go through physiological changes in order to transition from a freshwater environment to a saltwater marine environment. Some male parr may not go through smoltification and will become sexually mature and participate in spawning with sea-run adult females. These males are referred to as “precocious parr.”

First year parr are often characterized as being small parr or 0+ parr (4 to 7 cm long), where as second and third year parr are characterized as large parr (greater than 7 cm. long) (Haines 1992). Parr growth is a function of water temperature (Elliott 1991), parr density (Randall 1982), photoperiod (Lundqvist 1980), interaction with other fish, birds and mammals (Bjornn and Reiser 1991), and food supply (Swansburg *et al.* 2002). Parr 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 is often necessary as ice formation reduces total habitat availability (Whalen *et al.* 1999a).

Table 4.4. Parr classifications

		Baum (1997)	Danie <i>et al.</i> (1984)	Haines (1992)
Termed parr at:	Length (cm)		4	
Parr classes:	Small Parr (cm)			4 to 7
	Large Parr (cm)			≥7

4.4.1 Space and cover

The habitat in Maine rivers currently supports on average between 5 and 10 large parr (age one or older) per 100 square meters of habitat; or one habitat unit (Elson 1975; Baum 1997). The amount of space available for juvenile salmon occupancy is a function of biotic and abiotic habitat features including stream morphology, substrate, gradient and cover; the availability and abundance of food; and the makeup of predators and competitors (Bjornn and Reiser 1991). Further limiting the amount of space available to parr is their strong territorial instinct. Parr actively defend territories against other fish, including other parr, to maximize their opportunity to capture prey items. The size of the territory that a parr will defend is a function of the size and density of parr, food availability, the size and roughness of the substrate, and current velocity (Kalleberg 1958; Grant *et al.* 1998). The amount of space needed by an individual increases with age and size (Bjornn and Reiser 1991).

A field study conducted by Keeley and Grant (1995) found that juvenile salmon with mean fork length of 64mm required a mean area of 0.55sq.meters per fish. They also found that juvenile Atlantic salmon with fork length (FL) ranging from 29-145mm

required individual areas ranging from 0.02-7.46 square meters. Stradmeyer and Thorpe (1987) found that juveniles with a 130mm FL required 1.63 square meters and juvenile Atlantic salmon with a 100mm FL required 0.97 square meters area.

Often times cover, including undercut banks, overhanging trees and vegetation, diverse substrates and depths, and some types of aquatic vegetation, can make some habitats suitable for occupancy that would otherwise not be (Bjornn and Reiser 1991). Cover can provide a buffer against extreme temperatures; protection from predators; increase food abundance; and protection from environmental variables such as high flow events and sedimentation.

Table 4.4.1. Space and cover requirements of Atlantic salmon parr

		Baum (1997)	Elson (1975)	Keeley & Grant (1995)	Stradmeyer & Thorpe (1987)
Parr	Fork Length (mm)			29 to 145	100 to 130
	Area Size (m ²)			0.02 to 7.46	0.97 to 1.633
	Average # parr per habit unit*	5 to 10	5 to 10		

* One habitat unit is equivalent to 100m²

4.4.2 Mesohabitat and substrate preferences

Parr prefer, but are not limited to, riffle habitat associated with diverse rough gravel substrate. The preference for these habitats by parr that utilize river and stream habitats supports a sit-and-wait feeding strategy intended to minimize energy expenditure while maximizing growth. Overall, large Atlantic salmon parr utilizing river and stream habitats select for diverse substrates that predominately consist of boulder and cobble in the size range of 6.4 cm to 51.2 cm dia. (Symons and Heland 1978; Heggenes 1990; Heggenes *et al.* 1999). Symons and Heland (1978) conducted a study that examined 20 years worth of population data from the Miramichi River and tributaries of the Nashwaak River in Canada. Their data revealed that small parr in these drainages select shallow riffles, averaging 10 to 15 cm deep and a gravel substrate particle size between 1.6 and 6.4 cm in diameter. As parr grew, they selected for larger, more diverse substrate that contained boulders greater than 30 cm in diameter and riffle habitats greater than 30 cm deep. Coulombe-Pontbriand and LaPointe (2003) found that parr densities in the Bonaventure River in Quebec, Ca. were strongly correlated ($p < 0.05$) with boulder availability. Beland *et al.* (2004) found that approximately 95% of parr observed during electrofishing in the Narraguagus River were found in the vicinity of a discrete cover item (e.g., cobble or vegetation). When cobble was limited, parr often held position in the vicinity of rooted aquatic macrophytes.

Parr can also move great distances into or out of tributaries and main-stems to seek out habitat that is more conducive to growth and survival (McCormick *et al.* 1998). This occurs most frequently as parr grow and they move from their natal spawning grounds to areas that have much rougher substrate providing more suitable over-wintering habitat and more food organisms (McCormick *et al.* 1998). In the fall, large parr in some head-

water tributaries that are likely to become smolts the following spring, have been documented leaving summer rearing areas and migrating downstream, though not necessarily entering the estuary or marine environment (McCormick *et al.* 1998).

Though parr are typically stream dwellers, they also utilize pools, dead-waters and lacustrine habitats within a river system as a secondary nursery area after emergence (Cunjak 1996; Morantz *et al.* 1987; Erkinaro *et al.* 1998). It is known that parr will utilize pool habitats during periods of low water; most likely as refuge from high temperatures (McCormick *et al.* 1998); and during the winter months to minimize energy expenditure and avoid areas that are prone to freezing or de-watering (Rimmer *et al.* 1984). Salmon parr may also spend weeks or months in the estuary during the summer (Cunjak *et al.* 1989, 1990; Power and Shooner 1966).

Seasonal electro-fishing surveys conducted in Catamaran Brook, Canada, by Cunjak (1996) revealed a greater use of flats, pools and beaver ponds by parr during the winter months. Parr appear to select lacustrine environments more readily if predation and competition from other species is not a significant factor (Morantz *et al.* 1987). Saunders (1960) noted that in allopatric environments salmon occupied pool habitats more frequently than when brook trout were abundant in pools. Dempson *et al.* (1996) used various classification and maximum likelihood estimators to determine the extent that parr in the Conne River, Newfoundland used lacustrine environments. The analysis suggested that parr used lacustrine environments greater than 75% of the time for rearing. This clearly indicates the inherent variability and plasticity of Atlantic salmon life-history traits. In support of these findings are studies by Chadwick (1982) and Hutchings (1986) in which they observed both individual parr as well as small schools of parr in lakes in Newfoundland. Similarly, parr have also been documented utilizing ponds and lakes in Iceland (Einarsson *et al.* 1990), northern Finland (Erkinaro *et al.* 1995), northern Norway (Halvorsen and Jørgensen 1996) and Ireland (Matthews *et al.* 1997). The fact that parr will utilize lakes, ponds, pools, deadwaters and even estuarine environments reveals that salmon parr are highly adaptable to a wide range of habitat types, but may be limited to particular habitat features by the presence of predators and competitors. The introduction of predators and competitors can therefore limit the types of habitat available for occupancy.

Table 4.4.2. Substrate preferences of Atlantic salmon parr

		Symons & Heland (1978)
	Preferred rubble/cobble dia. (cm)	6.4 to 51.2
Small parr:	Riffle Depth (cm)	10 to 15
	Gravel diameter (cm)	1.6 to 6.4
Large parr:	Riffle Depth (cm)	≥30
	Boulder Diameter (cm)	≥30

4.4.3 Velocity

Morantz *et al.* (1987) developed habitat suitability curves for juvenile Atlantic salmon that utilized river and stream habitats, looking at substrate, flow and depth. Six rivers with variable morphological characteristics were used in the study. Morantz (1987) found that water velocity was the dominant physical factor influencing positioning for feeding and holding of juvenile Atlantic salmon given that velocity was the one variable that was relatively consistent across sites. Parr preferred areas of relative low to moderate velocity behind rocks or within eddies, that are located in areas of higher velocity as to allow parr to sit and wait for prey items to drift by. This sit and wait strategy adopted by salmon minimizes energy expenditure while maximizing opportunistic feeding on invertebrate drift (Kalleberg 1958; Everest and Chapman 1972).

Morantz *et al.* (1987) also developed nose velocity (the velocity experienced by an individual fish) suitability curves for juvenile Atlantic salmon. Morantz found that small parr most often utilized habitat where nose velocity ranged from 7 to 15 cm/sec. and large parr utilized habitat where velocities ranged from 10 to 20 cm/sec. Morantz went on to conclude that mean water velocity is less important than the water velocity at the fish's nose position, though parr avoid areas where mean water velocity exceeds 120 cm/sec..

Table 4.4.3. Velocity preferences of Atlantic salmon parr

		Morantz <i>et al.</i> (1987)
Nose Velocity:	Small Parr (cm/sec)	7 to 15
	Large Parr (cm/sec)	10 to 20

* Both small and large parr avoid velocities in excess of 120 cm/sec. (Morantz *et al.* 1987)

4.4.4 Temperature

Small parr and large parr have similar temperature tolerances (Elliott 1991). Water temperature influences growth, survival and behavior of juvenile Atlantic salmon. Juvenile salmon can be exposed to very warm temperatures (> 20°C) in the summer and near freezing temperatures in the winter, and have evolved with a series of physiological and behavioral strategies that enables them to adapt to the wide range of thermal conditions that they may encounter. Atlantic salmon are cold water fish and have a thermal tolerance zone where activity and growth is optimal (Decola 1970). Parr's optimal temperature for feeding and growth ranges from 15° to 19°C (Decola 1970). When water temperatures surpass 19°C, feeding and behavioral activities are directed towards maintenance and survival. During the winter when temperatures approach freezing, parr reduce energy expenditures by spending less time defending territories, feeding less and moving into slower velocity microhabitats (Cunjak 1996).

Though parr are capable of adapting to a broad range of temperatures, they do have an upper and lower temperature threshold for survival. A study conducted in Big Brook, Terra Nova National Park, Newfoundland, progressively acclimated parr to 27.5°C in freshwater. The upper lethal temperature was determined by probit analysis to be 27.8°C

+/- 0.41 after 10000 min exposure (Garside 1973). This limit is dependent on acclimation rates, more rapid acclimations may result in slightly higher upper lethal limits during shorter exposure times. Fry (1947) indicated graphically that Atlantic salmon acclimated to 25°C possessed an upper lethal temperature of about 28.5°C. This level was determined from shorter tests which produced median resistance intervals of less than 1000 min. It was assumed that it would not be possible to obtain less than 100% mortality in the testing range of 28-30°C for exposures of 10000 min (Garside 1973).

A study conducted by Elliott (1991) sought to construct a thermal tolerance polygon for juvenile Atlantic salmon using fish from two populations. Juvenile salmon were acclimated to 5°C temperature increments ranging from 5°C to 25°C as well as 27°C and were then subjected to 1°C positive or negative temperature increases to determine upper and lower limits for feeding and survival over periods of 10 min., 100 min., 1000 min., and 7 days. Elliott (1991) identified a mean upper incipient temperature tolerance of 22.5°C and a mean lower incipient temperature tolerance of 7.0°C by the cessation of feeding activity; a thermal stress response that influences both growth and survival of the fish.

Table 4.4.4. Temperature requirements of Atlantic salmon parr

	Decola (1970)	Elliot (1991)	Fry (1947)	Garside (1973)
Optimal Temperature Range(C°)	15 to 19			
Lower Lethal Temperature (C°)		*avg. 7		
Upper Lethal Temperature(C°):		*avg. 22.5	28.5	27.8 ±0.41
100% mortality at Temperature (C°)				28 - 30

*Upper and lower incipient temperature tolerances.

4.4.5 Dissolved Oxygen

Atlantic salmon parr require dissolved oxygen (DO) concentrations greater than 6 mg/l for adequate growth and general well being (Decola 1970). Parr require highly oxygenated waters to support their active feeding strategy. Though salmon parr can tolerate oxygen levels below 6mg/l, both swimming activity and growth rates are restricted. Oxygen consumption by parr is a function of temperature. As temperature increases, the demand for oxygen increases. Referred to as the limiting level, Decola (1970) described the oxygen level at which salmon parr are completely restricted and only capable of survival. For age 0 Atlantic salmon parr, the limiting oxygen concentration is 15°C is 1.51 mg/l and at 25°C is 2.85 mg/l. For age 1 parr and older, the limiting oxygen concentration at 10°C and 20°C are 2.15 mg/l and 2.9 mg/l, respectively.

Table 4.4.5. Oxygen requirements of Atlantic salmon parr (limiting Oxygen Concentrations (mg/l)):

		Decola (1970)
Age 0 Parr:	at 15°C	1.51
	at 25°C	2.85
Age 1+ Parr:	at 10°C	2.15
	at 20°C	2.9
General Oxygen Requirement (mg/l):		≥ 6

4.4.6 Sediments

The process in which sediments enter a river or stream can be either beneficial or detrimental to juvenile salmon. Bank erosion can be beneficial by providing new inputs of rubble and woody debris (Chamberlin 1991) which can in turn create shelter from predators; improve food availability from invertebrates that may take advantage of additions of organic material; and potentially create refuge from thermal stresses as the river or stream scours pools around debris deposits. Excessive bank erosion, on the other hand, can be detrimental as excess sediment is often transported downstream and deposited in a deposition zone that can severely impair habitats used for juvenile rearing. Additionally, sediment inputs increase the turbidity of the water. Most streams can be expected to experience periods of relatively high turbidity usually associated with storm events. Cases of excessively high turbidity have been found to disrupt behaviors of coho salmon in two studies. A study conducted by Bisson and Bilby (1982) reported that juvenile coho salmon avoided water with turbidities that exceeded 70 NTU (nephelometric turbidity units). Berg and Northcote (1985) reported that feeding patterns of juvenile coho were disrupted when turbid waters were in the range of 60 NTU for periods of 2.5 to 4.5 days. Short term disruptions in feeding behaviors may not be detrimental to growth and survival of parr, while frequent events or long term events could be.

4.4.7 Food

Atlantic salmon require sufficient energy to meet their basic metabolic needs for growth and reproduction (Spence *et al.* 1996). Parr largely depend on invertebrate drift for foraging, and actively defend territories to assure adequate space and food resources needed for growth. Parr feed on larvae of mayflies, 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). As parr grow, they will occasionally eat small fish, such as alewives, dace or minnows (Baum 1997).

Atlantic salmon attain energy from food sources that originate from both allochthonous (outside the stream) and autochthonous (within the stream) sources. What food is available to parr and how food is obtained is a function of a rivers hydrology, geomorphology, biology, water quality and connectivity (Annear *et al.* 2004). The

riparian zone is a fundamental component to both watershed and ecosystem function as it provides critical physical and biological linkages between terrestrial and aquatic environments (Gregory *et al.* 1991). Flooding of the riparian zone is an important mechanism needed to support the lateral transport of nutrients from the floodplain back to the river (Annear *et al.* 2004). Lateral transport of nutrients and organic matter from the riparian zone to the river supports the growth of plant, plankton and invertebrate communities. Stream invertebrates are the principle linkage between the primary producers and higher trophic levels, including salmon parr. Clearing of riparian zones or dramatic changes in the dominant riparian vegetation (*i.e.* deciduous to coniferous, or shrub to grassland) can result in changes in the principle energy sources (allochthonous or autochthonous) and temporal patterns of energy inputs (Spence *et al.* 1996). This may reduce food availability or force changes in the way that parr forage for food.

4.5 Smoltification

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). In order for parr to smoltify they must reach a critical size of 10 cm total length at the end of the previous growing season (Hoar 1988). During the smoltification process, parr markings fade and the body becomes streamlined and silvery with a pronounced fork in the tail. The 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). Smolt transition into seawater is usually gradual as they pass through a zone of mixing from freshwater to the marine environment that occurs most frequently in a river's estuary. Given that smolts undergo smoltification while they are still in the river, they are pre-adapted to make a direct entry into seawater with minimal acclimation (McCormick *et al.* 1998). This is necessary under some circumstances where there is very little transition zone between some coastal rivers and streams and the marine environment. 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% (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).

Table 4.5 (a). Atlantic salmon life history characteristics during parr-smolt transformation

	Hoar (1988)	Legault (2004)	Schafer & Elson (1975)	USASA C (2004)
Length at smoltification				
Avg. Length (cm)			12.5 to 15	
Critical Length (cm)*	10			
Length in Maine (cm)**				13 to 17

* Parr typically will not undergo the parr-smolt transformation unless they first reach a critical length

** Based on measurements from naturally reared Atlantic salmon

Table 4.5 (b). Survival from egg to smolt stage for Atlantic salmon

		Legault (2004)
Survival from egg to smolt:	estimated (%)	0.13 to 6.09
	90% C.I. (%)	0.5 to 3.5

4.5.1 Photoperiod, temperature and flow

The process of smoltification is triggered in response to environmental cues. Photoperiod and temperature have the greatest influence on regulating the smolting process. Increase in day length is necessary for smolting to occur (Duston and Saunders 1990).

McCormick *et al.* (1999) noted that in spite of wide temperature variations between rivers throughout New England, almost all smolt migrations begin around the first of May and are nearly complete by the first week in June. However, the time that it takes for the smoltification process to be completed appears to be closely related to water temperature; when water temperatures are increased, the smolting process is advanced, as evident by increases in Na⁺, K⁺ ATPase activity (Johnston and Saunders 1981; McCormick *et al.* 1998; McCormick *et al.* 2002). Osterdahl (1969) and Solomon (1978) reported that downstream smolt migration occurs when temperatures are at or slightly above 10°C. Whalen *et al.* (1999b) reported that smolt migration in the West River in Vermont began when temperatures exceeded 5°C and peaked when temperatures exceeded 8°C. They also reported that wild reared smolts originating from the warmer tributaries of the West River were more physiologically advanced and migrations began earlier compared to wild reared smolts originating from the colder tributaries.

In addition to playing a role in regulating the smoltification process, high temperatures also are responsible for the cessation of Na⁺,K⁺-ATPase activity of smolts. McCormick *et al.* (1999) found significant decreases in Na⁺,K⁺-ATPase activity in smolts at the end of the migration period, but found that smolts in warmer rivers had reductions in Na⁺,K⁺-ATPase activity earlier than smolts found in colder rivers. In Catamaran brook in New Brunswick and Conne River in Newfoundland where water temperatures remained cold, smolts retained Na⁺, K⁺-ATPase activity (McCormick *et al.* 1999). McCormick *et al.* (1998) stated that in warmer waters smolts will likely experience a narrower physiological smolt window than they otherwise would in cold water.

Flow does not play a role in the smoltification process, though it does appear to play an important role in stimulating a migration response. Whalen *et al.* (1999b) recorded that there was no apparent downstream migration following a high flow event in mid to late April in a Vermont river when water temperatures were between 3 and 6°C, however when water temperatures reached 8 to 12°C, small peaks in discharge resulted in corresponding increases in smolt migration.

Table 4.5.1. Temperature of smolt migration in the West River, VT

	Whalen <i>et al.</i> (1999)
Start: (C°)	5
Peaked: (C°)	8

4.5.2 Water chemistry

Atlantic salmon smolts are the most acid sensitive lifestage as the effects of acidity have been well documented to cause ionoregulatory failure in freshwater as a result of the inhibition of gill Na⁺,K⁺-ATPase activity which can cause the loss of plasma ions and may result in reduced seawater tolerance (Rosseland and Skogheim 1984; Farmer *et al.* 1989; Staurnes *et al.* 1996; Staurnes *et al.* 1993) and increased cardiovascular disturbances (Milligan & Wood 1982; Brodeur *et al.* 1999). Parr undergoing parr/smolt transformation become more sensitive to acidic water, hence water chemistry that is not normally regarded as toxic to other salmonids may be toxic to smolts (Staurnes *et al.* 1993, 1995). This is true even in rivers that are not chronically acidic and not normally considered as being in danger of acidification (Staurnes *et al.* 1993, 1995).

Atlantic salmon smolts are particularly vulnerable to low pH especially in combination with elevated levels of monomeric labile species of aluminum and low calcium (Rosseland and Skogheim 1984; Rosseland *et al.* 1990; Kroglund and Staurnes 1999). Kroglund and Staurnes (1999) observed mortality of Atlantic salmon smolts held in soft water with a pH less than 5.8 containing 30 – 90 µg inorganic monomeric aluminum. Haines *et al.* (1990) found that Atlantic salmon smolts held in artificial stream channels in Eastern Maine and exposed to pH less than 5.5 and exchangeable Al concentrations greater than 200 µg/l experienced osmoregulatory stress based on declines of sodium and chloride blood plasma ions and increases in hematocrit. Magee *et al.* (2003) studied the effects of episodic acidification on Atlantic salmon smolts and found that Atlantic smolts exposed to pH ~5.2 over 48 hours experienced reductions in hematocrit, increases in plasma sodium, chloride and potassium levels, and suffered mortalities. Liebich *et al.* (2007 unpublished data) recently conducted an investigation in Eastern Maine in which Atlantic salmon smolts exposed to pH between 5.5-5.8 and total aluminum 80-168 µg/L in a clear water stream (DOC 1.6-1.9 mg/L) experienced 66% mortality in a period of less than 96 hours whereas no mortality was observed when smolts were exposed to pH as low as 5.0 -5.8 and total aluminum 93-222 µg/L in streams that were moderately colored (DOC 11-15.5 mg/L). Numerous studies have shown that organic complexes between humic substances and trace metals can occur (Thurman 1985; Driscoll 1980; Kullberg *et al.* 1993), and that reactions with DOC constitute an important mechanism in

reducing the toxic effects of aluminum. Supporting observations by Liebich et al. (2007), these findings suggest that DOC may be mitigating the bio-availability of toxic labile monomeric aluminum in moderately colored watersheds throughout eastern Maine.

Table 4.5.2. Effects of varying water chemistries on Atlantic salmon smolts

		Kroglund & Staurnes (1999)	Liebich <i>et al.</i> (unpublished data)
Smolt Mortality:	pH	≤5.8	
	Al (µg/L)	30 to 90	
Clear Water:	pH		5.5 to 5.8
	Al (µg/L)		80 to 168
	Mortality (%)		66
	Time (hours)		≤96
Colored Water:	pH		5.0 to 5.8
	Al (µg/L)		93 to 222
	Mortality (%)		0
	Time (hours)		96

4.5.3 Olfactory imprinting

Evidence reveals that olfactory imprinting is particularly important during the parr – smolt transformation period. Hansen *et al.* (1993) studied homing behaviors of smolts in Norway and found that smolts released at sea returned as adults to the point where they were released and then indiscriminately entered nearby streams to spawn. However, smolts released at the mouth of a river returned to that river as adults independent of their genetic origin. Furthermore, fish that were reared in the river, yet were deprived of outward sea migration as smolts by being transported and released as post-smolts to their feeding grounds north of the Faroe Islands, were not documented to have returned to freshwater to spawn.

4.5.4 Migration requirements

Migration is described by McCormick *et al.* (1998) as being the hallmark of a salmon’s life history. Adult salmon must have access to rivers and streams from the ocean to spawn, equally important is a smolts ability to successfully migrate out to the ocean. As noted in the previous sections, delay of migration has the potential to reduce survival of out-migrating smolts as they have a limited physiological window of opportunity in which they are capable of transitioning from freshwater to saltwater.

Seaward migration is initiated by increases in river flow and temperature in the early spring (McCleave 1978; Thorpe and Morgan 1978). Migration through the estuary is believed to be the most challenging period for smolts (Lacroix and McCurdy 1996), and the length of estuarine residence depends on; estuary size, shape, productivity, water flow patterns, velocity, salinity and temperature (Thorpe 1994). Although it is difficult to

generalize migration trends because of the variety of estuaries, Atlantic salmon post-smolts tend to move quickly through the estuary, and enter the ocean within a few days or less (Lacroix *et al.* 2004; Hyvarinen *et al.* 2006; McCleave 1978). In the upper estuary, where river flow is strong, Atlantic salmon smolts use passive drift to travel (Moore *et al.* 1995; Fried *et al.* 1978; LaBar *et al.* 1978). In the lower estuary, smolts display active swimming, although their movement is influenced by currents and tides (Lacroix and McCurdy 1996; Moore *et al.* 1995; Holm *et al.* 1982; Fried *et al.* 1978). Several studies suggest that there is a “survival window” which is open for several weeks in the spring, and gradually closes through the summer, during which time salmon can migrate more successfully (Larsson 1977; Hansen and Jonsson 1989; Hansen and Quinn 1998). Although some individuals seem to utilize a period of saltwater acclimation, some fish have no apparent period of acclimation (Lacroix *et al.* 2004). Stefansson *et al.* (2003) found that post-smolts adapt to seawater without any long-term physiological impairment.

4.6 Marine Habitat

The marine life history of Atlantic salmon of U.S. origin is not well understood. 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 (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, and the North Atlantic Salmon Working Group (ICES-NASWG).

4.6.1 Post smolt migration and behavior

The early migration of post-smolts out of the coastal environment is generally rapid, within several tidal cycles, and follows a direct route (Hyvarinen *et al.* 2006; Lacroix and McCurdy 1996; Lacroix *et al.* 2004, 2005). Post-smolts generally travel out of coastal systems on the ebb tide, and may be delayed by flood tides (Hyvarinen *et al.* 2006; Lacroix and McCurdy 1996; Lacroix *et al.* 2004, Lacroix and Knox 2005), although Lacroix and McCurdy (1996) found that post-smolts exhibit active, directed swimming in areas with strong tidal currents. Studies in the Bay of Fundy and Passamaquoddy Bay suggests that post-smolts aggregate together and move near the coast in “common corridors”, and that post-smolt movement is closely related to surface currents in the bay (Hyvarinen *et al.* 2006; Lacroix and McCurdy 1996; Lacroix *et al.* 2004). European post-smolts tend to use the open ocean for a nursery zone, while North American post-smolts appear to have a more near-shore distribution (Friedland *et al.* 1993). Post-smolt distribution may reflect water temperatures (Reddin and Shearer 1987) and/or the major surface-current vectors (Lacroix and Knox 2005). Post-smolts live mainly on the surface of the water column and form shoals, possibly of fish from the same river (Shelton *et al.* 1997).

During the late summer/autumn of the first year, North American post-smolts are concentrated in the Labrador Sea and off of the west coast of Greenland, with the highest

concentrations between 56 and 58°N (Reddin 1985; Reddin and Short 1991; Reddin and Friedland 1993). The salmon located off of Greenland are composed of both ISW and MSW immature salmon from both North American and European stocks (Reddin 1988; Reddin *et al.* 1988). The first winter at sea regulates annual recruitment, and the distribution of winter habitat in the Labrador Sea and Denmark Strait may be critical for North American populations (Friedland *et al.* 1993). In the spring, North American post-smolts are generally located in the Gulf of St. Lawrence, off the coast of Newfoundland, and on the east coast of the Grand Banks (Reddin 1985; Dutil and Coutu 1988; Ritter 1989; Reddin and Friedland 1993; Friedland *et al.* 1999).

Some salmon may remain at sea for another year or more before maturing. After their second winter at sea, the salmon over-winter in the area of the Grand Banks before returning to spawn (Reddin and Shearer 1987). Reddin and Friedland (1993) found non-maturing adults located along the coasts of Newfoundland, Labrador and Greenland, and in the Labrador and Irminger Sea in the later summer/autumn.

4.6.2 Estuary influence on adult returns

Atlantic salmon stay at sea for 1-4 years before maturing, and the shorter their marine stay, the higher the chance of survival and return (Hansen *et al.* 1993; Jonsson *et al.* 1991, 2003; Erkinaro *et al.* 1997). The homing migration process is not well understood (Hansen and Quinn 1998), although it is generally accepted that oceanic migration is led by compass and navigational systems, while estuarine and riverine migration are guided by odor imprints from the natal river (Carlin 1967; Hasler and Scholz 1983; Dittman and Quinn 1996). Migration of adults through the estuary is largely by passive drift, and fish generally drift with flood tides and stem ebb tides (McCleave 1978; Stasko 1975; Smith and Smith 1997). The relationship between salmon movement and tidal phase decays as the fish move up the estuary (Smith and Smith 1997).

Adult salmon often delay migration when they enter fjords or estuaries. This may be because they require time to locate their natal rivers (Hansen *et al.* 1993), are waiting for suitable conditions for upstream migration (Jonsson *et al.* 1990) or are undergoing maturation processes or osmoregulatory adaptation. McCleave (1978) found that some adults move back to sea during periods of low-flow in the summer, and may make several passes into the estuary and back to sea before entering freshwater. Adult migration up the estuary is predominantly nocturnal (McCleave 1978; Smith and Smith 1997) with increases occurring during periods of increased water flow (McCleave 1978).

4.6.3 Temperature and climate

The effects of temperature and climate on Atlantic salmon are reviewed by Friedland *et al.* (1993), Hansen and Quinn (1998), Jonsson and Jonsson (2004a), Reddin (1988), Reddin and Friedland (1993), and Ritter (1989). By comparing sea surface temperature (SST) with experimental catch rates, and by attaching temperature monitors to fish, researchers have determined that the preferred temperature range for salmon in the spring falls between 7 – 13°C, although most catches occur between 4 – 8°C (Friedland *et al.* 1993; Friedland and Reddin 1993; Reddin and Shearer 1987; Reddin 1988; Reddin and Short 1991; Reddin *et al.* 1997). The movement of salmon into waters around

Newfoundland correlates with the presence of a 4°C isotherm (Reddin and Friedland 1993). Location of salmon related to these “thermal habitats” suggests that salmon can alter their migratory routes depending on SST (Reddin and Shearer 1987; Reddin and Friedland 1993). The timing of salmon entrance into coastal waters has also been linked with environmental conditions of coastal waters (Reddin and Friedland 1993; Reddin *et al.* 1997).

Table 4.6.3. Temperature preference of Atlantic salmon at sea

	Friedland <i>et al.</i> (1993)	Friedland & Reddin (1993)	Reddin & Shearer (1987)	Reddin (1988)	Reddin & Short (1991)	Reddin <i>et al.</i> (1997)
Preferred temperature at sea (C°)	7 to 13	7 to 13	7 to 13	7 to 13	7 to 13	7 to 13
Temperature that provided most sea caught fish (C°)	4 to 8	4 to 8	4 to 8	4 to 8	4 to 8	4 to 8

4.7 Kelts

Atlantic salmon are iteroparous (*i.e.* capable of spawning more than once), unlike Pacific salmon which are semelparous. After spawning, Atlantic salmon may either return to sea immediately or remain in freshwater until the following spring before returning to the sea (Fay *et al.* 2006). From 1967 to 2003, approximately 3% of the wild and naturally reared adult returns in rivers where adult returns are monitored were repeat spawners (USASAC 2004).

Upon returning to the marine environment, post – spawned salmon will resume feeding and will recover its silver color (Fay *et al.* 2006). 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 of 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.

Section 5: Human activities that affect habitat features

Anthropogenically induced disturbances can have detrimental effects that both directly and indirectly influence aquatic environments. For instance, land use practices such as dam construction, urbanization, forestry, and agriculture may influence aquatic environments by altering the natural hydrological processes within a watershed. Alternatively, activities resulting in introductions of toxic materials such as pesticides and herbicides to the water column may disrupt natural biological processes of various fish species. Whereas activities such as dam construction, road crossings, dredging, and shoreline armoring may alter physical habitat features. In addition, activities such as shoreline development and the construction of over-water structures have the potential to alter migration corridors used by salmonids, as well as various other aquatic organisms. Because of the potentially disastrous consequences of anthropogenically induced habitat alterations, it is essential the implications of various commonly occurring activities that affect habitat features are understood. The following review is not fully inclusive of all activities which affect habitat features, but rather a summary of primary human activities that can have detrimental effects upon the ecological processes of aquatic habitats, as well as the biota existing in those habitats.

5.1 Effects of dams

Dams are the greatest impediment to self-sustaining Atlantic salmon populations in Maine (NRC 2003). Dams obstruct passage for migratory fish and degrade habitat through alterations of natural hydrologic, geomorphic and thermal regimes (American Rivers *et al.* 1999; Heinz Center 2002; NRC 1996, 2004; Fay *et al.* 2006). Dams are also the most significant contributing factor to the loss of salmon habitat connectivity within the range of the DPS (Fay *et al.* 2006).

5.1.1 Configuration of dams in the Gulf of Maine DPS

The following section was largely pulled from section 8.1.2.2.1 of the 2006 Atlantic Salmon Status Review (Fay et al. 2006) with the permission of the chair. The Status Review provides an excellent overview of dams in the Gulf of Maine DPS and their effects on Atlantic salmon populations.

In the early 1600's the nation's first dam was built in Kittery, Maine to support a water powered mill (Hasbrouck 1995). Over the next 200 years, dams were constructed throughout Maine to support water mills that ground grain and sawed logs. By the 1800's larger dams on mainstem rivers were being built to support textile mills and other forms of manufacturing. At about the same time, dams were being constructed to support Maine's booming logging industry (Hasbrouck 1995). By the early to mid 1900's many new dams, as well as many of the larger dams that once supported manufacturing, were being constructed or transformed for electrical power generation (Hasbrouck 1995). Throughout the 1800s and 1900s, efforts to require upstream fish passage at these dams were largely ignored by dam operators even though the biological requirements of migratory fish were understood at that time.

Today, many of the same dams that historically played an important role in regulating flows for logging and for saw mill operations are still being maintained for power generation, flow or flood control, or maintenance of water levels in lakes and ponds in order to support a water supply for industrial and municipal purposes as well as recreational boating, hunting and fishing. As a result, there are 443 dams present within the range of the GOM DPS (Figure 5.1.1; MEGIS 2006). In addition, there are a large number of dams less the four feet in height, however a thorough inventory of these structures does not currently exist (Fay *et al.* 2006). Dams throughout the DPS, individually and collectively, have a significant impact on salmon populations and recovery efforts.

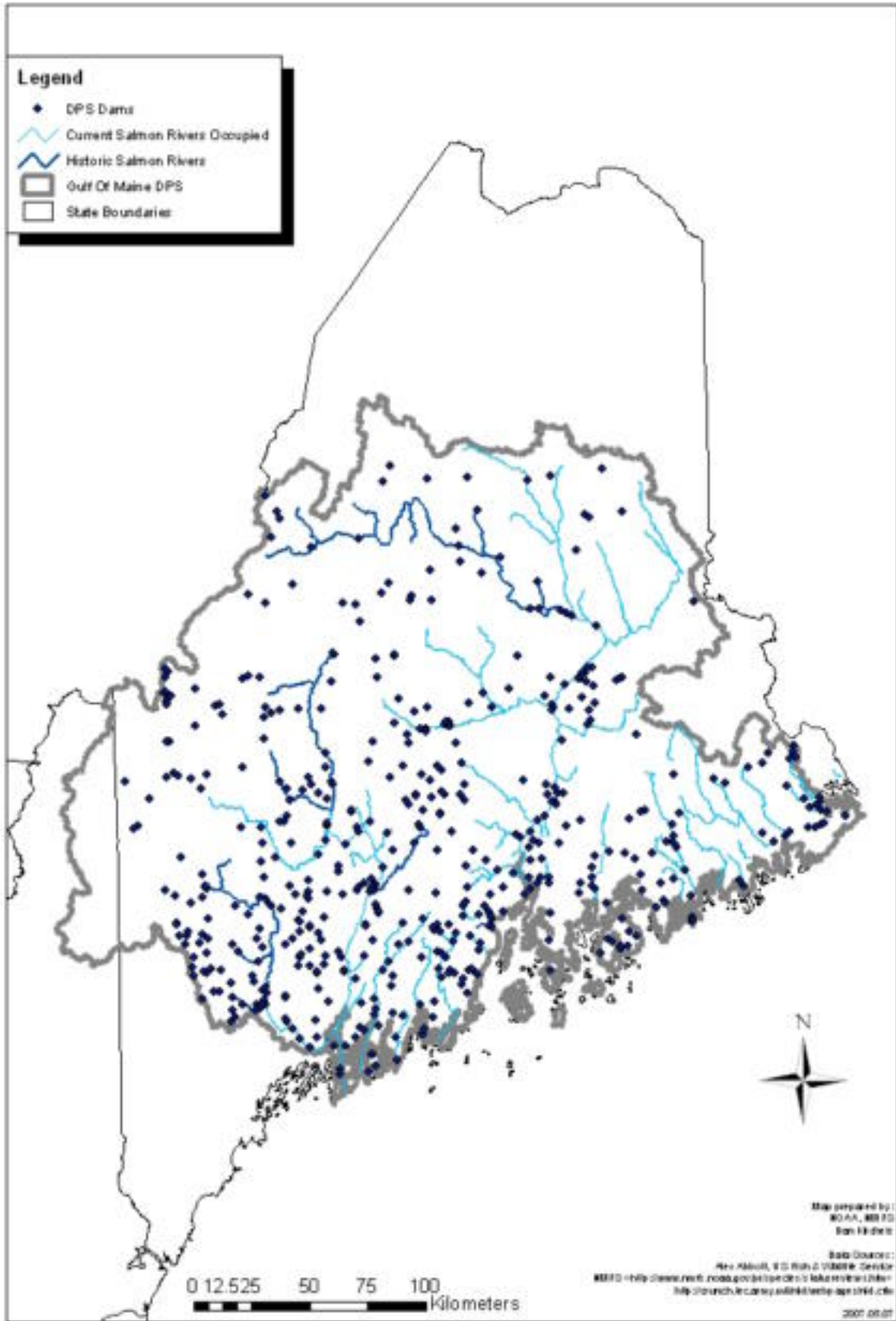


Figure 5.1.1. Dams within the GOM DPS over four feet in height.

Penobscot River Watershed

The Penobscot River presently has upstream fish passage facilities on most hydroelectric facilities; exceptions being the Stillwater, Orono, Milo and Sebec dams. As a result, approximately 80% of the 100,000 metric units of potentially available rearing habitat in the Penobscot is presently accessible to Atlantic salmon. However, salmon must pass several main stem dams to access most reaches. For example, 76% of all accessible habitat units are above at least four dams. Furthermore, 100% 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) is above at least four dams, and an estimated 51% of that is above at least five dams.

The West Branch of the Penobscot River is currently inaccessible to anadromous fish because there is no fish passage at the four lowermost dams. These dams exclude Atlantic salmon from approximately 28,000 units of rearing habitat within the West Branch (USFWS 2004), or 28% of the potential rearing habitat within the Penobscot drainage. 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 sub-drainage 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. The importance of having the West Branch available to the GOM DPS metapopulation of salmon, while unknown, could be significant at this broader scale (refer to Section 3.3, Habitat Availability, Accessibility, and Metapopulation Structure of the 2006 status review for more information).

Kennebec River Watershed

Over 100,000 metric units of rearing habitat exist in the Kennebec river. However, until recently, upstream fish passage for Atlantic salmon had not been available for over 100 years in most of the Kennebec River. In July 1999, the first hydroelectric dam (Edwards) on the Kennebec River was breached to allow anadromous fish access into 17 miles of spawning and rearing habitat. Since this time, several more projects aimed at diadromous fish passage have occurred within the Kennebec watershed. In 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”. As a result, the Lockwood dam currently contains a fish lift with trap and truck facilities and Atlantic salmon captured at the Lockwood dam are transported upstream to locations with suitable habitat (e.g., the Sandy River). Concurrently, in the summer of 2006, the Sandy River Project dam owned by Madison Electric was removed. Removal of the Sandy River Project dam has opened up 52 miles of Atlantic salmon and American eel habitat in the mainstem of the Sandy River along with another 186 miles of habitat within the tributaries. In addition to the new passage facilities at the Lockwood dam and removal of the Sandy River Project dam, a fish pump has been installed at the Ft. Halifax Dam on the Sebec River (a tributary to the Kennebec). Fish pump technology has not been demonstrated to successfully pass

upstream migrating Atlantic salmon, however, FPL Energy expects to begin removal of the Ft. Halifax dam no later than 2008.

At present, only the Lockwood dam on the Kennebec has upstream fish passage facilities for Atlantic salmon (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 dam.

Based upon various biological triggers established by state and federal resource agencies in the aforementioned Settlement Accord, the next main stem dam upstream of Lockwood (Hydro - Kennebec) 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.

Androscoggin River Watershed

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

Other Watersheds

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. Dams located on tributary streams of Atlantic salmon rivers are also likely affecting water quality, hydrology, and ecology of the main stem rivers. Of the numerous small non-hydro dams in the DPS, many are at headwater ponds and lakes limiting access to anadromous alewives that depend on lakes and ponds for spawning as well as Atlantic salmon adults, kelts, and juvenile salmon that may have used lakes and ponds frequently for thermal refuge and feeding.

5.1.2 Fish Passage

Dams can prevent or impair fish passage both up and downstream (Fay *et al.* 2006). If dams do not have fish passage facilities, or the facilities are improperly designed or maintained, access to habitat upstream of the dam can be eliminated (Fay *et al.* 2006). Even installation of passage facilities will not ensure passage, as no fishway is 100% efficient. As a result, the more fishways encountered by a migrating salmon, the less likely they are to achieve effective passage; hence, losses are cumulative. If salmon cannot access upstream habitat they are not able to spawn, this will directly impact the population. Presently, approximately 44-49% of all historical Atlantic salmon habitat is not accessible due to the lack of upstream fish passage.

Dams can also affect downstream migration through direct mortality and by hindering migratory movement. Hydroelectric dams can harm salmon through entrainment or impingement. Entrainment occurs when downstream migrants are injured by passing through turbines, whereas, impingement occurs when fish are injured by coming into contact with a screen, trash rack or debris at intake (Fay *et al.* 2006). Both entrainment and impingement can cause mortality as well as prevent fish passage.

Impaired fish passage can also delay timely movement of smolts. Delayed migration can lead to direct mortality through increased predation (Blackwell and Juanes 1998), and can also reduce physiological health or preparedness for marine entry and migration (Budy *et al.* 2002). Delays in migration may cause salmon to lose physiological smolt characteristics due to high water temperatures during spring migration, and can result in progressive misalignment of physiological adaptations to seawater entry thereby reducing smolt survival (McCormick *et al.* 1999). Lastly, because Atlantic salmon often encounter multiple dams during their migratory life cycle, losses are cumulative and often biologically significant (Fay *et al.* 2006).

5.1.3 Physical habitat

Dams can disrupt natural ecological processes as well as dramatically alter the river or stream habitat both up and downstream of the dam. The construction of dams creates pools or larger impoundments and results in the flooding of riparian habitat. Anadromous salmon are not adapted to live in the pools and reservoirs formed behind dams, and the inundation of once suitable habitat by a reservoir results in unsuitable habitat for spawning and juvenile rearing (NRC 2004).

5.1.4 Sediment transport

The alteration in flow created by dams both upstream and downstream of the dam results in alterations of natural sedimentation and erosion processes. As a result, dams have the ability to prevent the downstream movement of LWD, gravel, and sediment within rivers, lakes, and streams. Stream-flow depletion may cause sediments to accumulate in downstream reaches or in the pool or reservoir (Spence *et al.* 1996). Many species of algae, phytoplankton, zooplankton, benthos, aquatic insects, and fish are adversely affected by suspended and shifting sediments (Iwamoto *et al.* 1978), which may have direct and indirect impacts on salmon populations.

5.1.5 Stream temperature

The slowing of free-flowing water by dams can change stream temperature both up and downstream. Increases in the size of pools and impoundments formed behind dams relative to streamflow results in lengthened water residence times, increased water depth, and decreased daily temperature fluctuations. Water in deep reservoirs has a tendency to become thermally stratified into a warm, well-mixed upper layer (epilimnion), a cold, dense bottom layer (hypolimnion) and an intermediate layer (metalimnion) with a strong temperature gradient (thermocline) (Berkamp *et al.* 2000). If water is released from the epilimnion, downstream water temperatures may increase, while release of water from the hypolimnion layer can decrease downstream temperatures (Spence *et al.* 1996). Seasonal temperature regimes of the river may also be altered as water is released

throughout the year. Alterations in stream temperatures can affect salmon development (Spence *et al.* 1996).

5.1.6 Stream flow and water levels

Dams and river impoundments affect both the total volume of water available to fish and the seasonal distribution of flow (Spence *et al.* 1996). Flows in some reaches of river have been entirely bypassed as a result of dam construction resulting in dewatered or minimum flows in Atlantic salmon habitat. Changes in the quantity and timing of stream-flow alter the velocity of streams, which affects the ecology and biota of the river. Fluctuating water levels may delay migration, impact breeding conditions, and reduce or expose spawning and rearing habitat (Beiningen 1976). Lower water levels may also concentrate fish and increase predation and competition (Spence *et al.* 1996). In addition, the distribution, abundance and composition of many benthic invertebrate and fish communities are determined by water velocity.

5.1.7 Disease

Salmon inhabiting lakes and reservoirs experience more disease than fish in free-flowing water (Bell 1986). Dams can facilitate disease in salmonids by altering temperature regimes, lowering water levels, reducing flow velocities, creating habitat for intermediate hosts, and concentrating organisms; all of which facilitate the transmission of certain pathogens.

5.1.8 Water Chemistry

Many chemical and biological changes occur in deep, thermally stratified reservoirs. Dissolved oxygen is often high in the surface layers where phytoplankton are abundant, while lack of sunlight and mixing often causes anoxic conditions in the bottom layer (Berkamp *et al.* 2000). When water is released over the top of a dam it can become supersaturated with nitrogen, oxygen and other dissolved gases, which can cause gas bubble disease in salmonids downstream of the impoundment (Spence *et al.* 1996).

The creation of impoundments through dam construction can result in eutrophication. Eutrophication occurs as large influxes of organic material enter a reservoir. Eutrophication can cause algal blooms that may lead to oxygen depletion within the reservoir during decomposition of this excess organic matter. The water quality and prey available to salmon change in these areas, as do the predation and competition threats (NRC 2003).

5.2 Effects of contaminants

The addition of chemicals, metals, and other pollutants (including thermal pollution) through wet or dry acid deposition, or through point source or non-point source pollution, can change the chemical composition of the water, which in turn can lead to negative impacts to organism present within an aquatic ecosystem. Chemicals from agricultural practices, industrial pollution, and residential and urban development can enter a stream through direct application and drift, or through ephemeral stream channels, overland flow, or groundwater leaching (Norris *et al.* 1991). The route in which chemicals enter the stream can influence the extent of exposure for aquatic organisms. Direct application

and drift can result in the highest concentrations entering the stream whereas leaching often results in only trace amounts of chemicals entering the stream (Norris *et al.* 1991). The effects of chemicals vary widely and are dependent on various environmental factors, application methods, weather conditions and chemical formulations. Salmonid LD50s are known for most pesticides used in Maine agriculture, however, many lifestages remain untested and the chronic or sublethal effects of these chemicals on aquatic ecosystems are not well understood (Dill *et al.* 2001).

5.2.1 Biota

Pesticides

The Atlantic salmon habitat features affected most by agricultural pesticides are aquatic plants that provide cover and secondary forage, and aquatic invertebrates that provide food. The use of pesticides can affect all levels of the ecosystem including plants, invertebrates, fish, amphibians, and mammals. Impacts to one or any trophic level within an aquatic ecosystem may have numerous repercussions for Atlantic salmon. The indirect effects of pesticides include modification of habitat, prey species, and other non-target organisms (Fay *et al.* 2006). Insecticides can modify habitats by reducing both terrestrial and aquatic insects that, in turn, can alter or decrease a salmon's food supply (Norris *et al.* 1991). Pesticides that do not cause direct mortality of invertebrates might bioaccumulate in many prey species. If contaminated prey are consumed, the toxic effects of pesticides may be directly realized by predators. Once present within an organism, pesticides can function as endocrine disruptors which alter sex hormone systems in animals (Dill *et al.* 2001). For Atlantic salmon, the most toxic pesticides are insecticides, followed by fungicides and herbicides (Dill *et al.* 2001). Although the direct toxic effects of pesticides to Atlantic salmon are minimal when they are applied at recommended rates and concentrations in areas with sufficient riparian buffers, improper application may introduce these toxins into the aquatic environment at harmful levels (Fay *et al.* 2006).

The extent of a pesticide's direct effects to Atlantic salmon depends primarily on the concentration and duration of exposure, as well as toxicity, water quality and stream flow velocity (Fay *et al.* 2006). Pesticides may reduce salmon survivorship as well as reproductive ability by impairing the olfactory and pheromonal priming systems (Moore and Waring 1996). Endocrine disrupting pesticides such as atrazine, DDT (dichloro-diphenyl-trichloroethane), dioxin and PCBs (polychlorinated biphenyls), are believed to affect smoltification in Atlantic salmon by disrupting hormone systems that facilitate physiological adaptations to seawater (Fairchild *et al.* 1999). Even combinations of low levels of nonphenol pesticides such as atrazine may have synergistic effects on salmon vitellogenesis and smoltification (Fairchild *et al.* 2002; Madsen *et al.* 1997). These effects are detailed more extensively in Fay *et al.* (2006). Organophosphate pesticides have been found to impair the response of adult male Atlantic salmon to female pheromones and have the potential to reduce spawning and fertilization rates (Moore and Waring 1996). Studies on Pacific salmon have indicated that the olfactory inhibition caused by organophosphate pesticides can also impair alarm responses and homing behavior (Scholz *et al.* 2000).

Herbicides

Herbicides can have lethal as well as a variety of sublethal affects on Atlantic salmon. Sublethal affects include reduced growth, decreased reproductive success, altered behavior, and reduced resistance to stress (Beschta *et al.* 1995). In addition to direct affects, herbicides may indirectly affect Atlantic salmon through a reduction in in-stream and riparian cover and shade, this may lead to secondary reactions that influence food supply and overall ecosystem function (Norris *et al.* 1991). For example, herbicide application can eliminate the growth of terrestrial vegetation in the riparian zone, an impact which in itself may severely alter many important ecological processes.

5.3 Effects of agriculture

Crop and pasture land in Maine has declined by about 900,000 acres since the 1950s to an estimated 536,000 acres throughout Maine in 2002 (USDA Census of Agriculture 1999, 2002). Most of the agricultural land in Maine was initially forested and was converted to farms during the late 19th century (NRC 2003). Although much of this area has been reclaimed by second

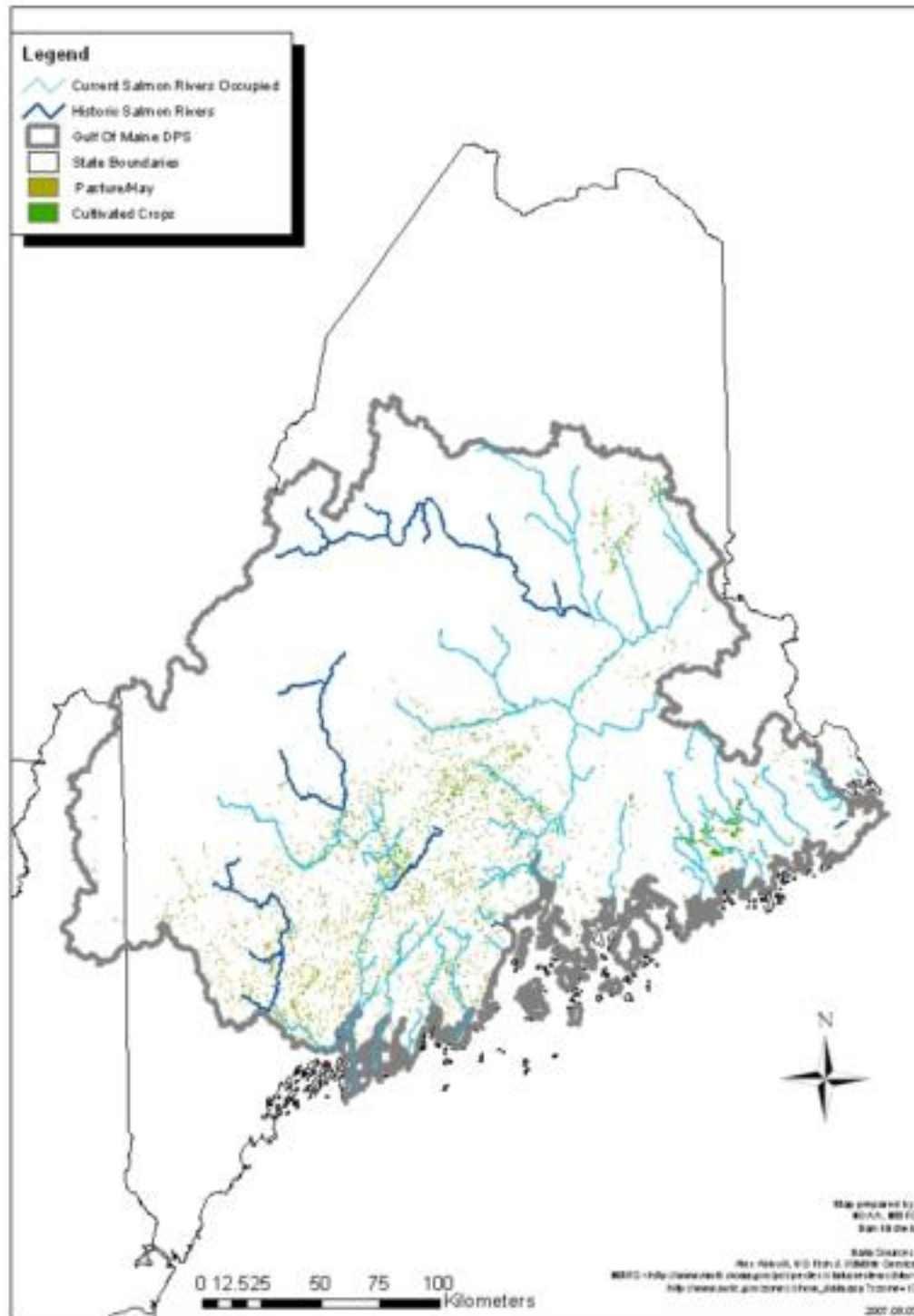


Figure 5.3. Agriculture lands as identified in the 2001 National Land Cover Dataset as either being Pasture/Hay or Cultivated Crops

growth forest, the land that has remained in agriculture has caused long term alterations to the landscape. The effects of sustained agriculture on the landscape can often be more severe than the effects of logging given that soil disturbances are often more frequent and changes in vegetation are often permanent (Spence *et al.* 1996).

Within the range of the Gulf of Maine DPS, Washington, Androscoggin, Penobscot and Kennebec Counties lead in agricultural production, growing a variety of products including blueberries, hay, potatoes, corn and oats or raising livestock and poultry (USDA 2002 Census of Agriculture). Blueberry culture is the primary form of agriculture in watersheds east of the Penobscot River, while livestock and crop production are the primary forms of agriculture in the Penobscot basin and watersheds south and west of the Penobscot (Flanagan *et al.* 1999; Fay *et al.* 2006).

5.3.1 *Physical habitat*

Physical disturbances caused by livestock and equipment associated with agricultural practices can directly impact the habitat of aquatic species (USEPA 2003). Traditional agricultural practices require repeated mechanical mixing, aeration and application of fertilizers and pesticides to soils. These activities alter physical soil characteristics and microorganisms. Tillage aerates the upper soil, but causes compaction of finely textured soils below the surface, which alters water infiltration. Use of heavy farm equipment and construction of roads also compact soils, decreases water infiltration, and increases surface runoff (Spence *et al.* 1996). Agricultural grazing and clearing of riparian vegetation can expose soils and increase soil erosion and sediment inputs into rivers.

Agricultural practices may also reduce habitat complexity and channel stability through physical stream alterations such as: channelization, bank armoring, and removal of large woody debris (LWD) and riparian vegetation (Spence *et al.* 1996). These effects often result in streams with higher width to depth ratios which exhibit more rapid temperature fluctuations and may also be subjected to increased armoring and embeddedness as a function of decreased water velocity (Fay *et al.* 2006).

5.3.2 *Hydrology*

Agricultural practices can affect stream hydrology through removal of vegetative cover, soil compaction, and irrigation. Removal of vegetation and soil compaction can increase runoff which can increase the frequency and intensity of flooding (Hornbeck *et al.* 1970). Increases in frequency and intensity of flood events can increase erosion, increase sedimentation and scour. Direct water withdrawals and ground-water withdrawals for crop irrigation can directly impact Atlantic salmon habitat by depleting stream-flow; a direct effect that can impact salmon habitat (MASTF 1997; Dudley and Stewart 2006; Fay *et al.* 2006). Currently, the cumulative effects of individual irrigation impacts on Maine rivers is poorly understood, however, it is known that adequate water supply and quality is essential to all life stages of Atlantic salmon and life history behaviors including adult migration, spawning, fry emergence and smolt emigration (Fay *et al.* 2006).

Agricultural irrigation has been increasing throughout the range of the GOM DPS (Fay *et al.* 2006). Irrigation is used to enhance potato and corn production in central Maine and blueberry production in eastern Maine. The Maine Department of Agriculture and Natural Resource Conservation Service have funded irrigation projects that include pond construction and construction of irrigation systems (Fay *et al.* 2006). In eastern Maine, the number of groundwater wells used for irrigation of blueberries is increasing (Dudley and Stewart 2006) as the acreage of crop lands expand and in an effort to reduce direct withdrawals from nearby rivers. Dudley and Stewart (2006) assessed surface water data collected from two USGS stream-flow gaging stations on the Pleasant River in Eastern Maine to determine if pumping from a well positioned near the river had an effect on flow. They found that on days when the well was being pumped the stage relationship between the two gaging stations was significantly different than on days when the well was not being pumped. The range of stream-flow depletion at the site varied with stage and ranged from 0.3 to 0.8 cubic feet per second with a relative short-term stream-flow depletion of approximately 1.7 to 10 percent. Neither the long-term or cumulative effects of well pumping on stream flows in the Pleasant River were assessed by Dudley and Stewart (2006), however, these impacts could be significant to listed Atlantic salmon.

5.3.3 Water quality

Agriculture is the most wide-spread source of non-point source pollution impairing rivers and lakes in the U.S. (USEPA 2003). The primary pollutants associated with agriculture are nutrients, sediments, animal wastes, salts and pesticides (USEPA 2003). Nitrogen (N) and phosphorous (P) are two major nutrients most commonly associated with agriculture that degrade water quality (USEPA 2003). The primary sources of nutrients associated with agriculture are commercial fertilizers and animal manure (USEPA 2003). The most common transport mechanism of nutrients into waterbodies is through surface water runoff, though nutrient inputs can also occur through groundwater infiltration (USEPA 2003). Both nitrogen and phosphorous are present in aquatic environments at levels typically below 0.3 and 0.001 mg/l respectively and are essential for aquatic plant growth and ecosystem health (USEPA 2003). However, elevated levels of nitrogen and phosphorous from agricultural inputs can dramatically increase aquatic plant productivity that can result in eutrophication of the waterbody that can deplete oxygen supplies, reduce quality of fish habitat, promote propagation of fish better adapted for reduced oxygen environments, and can increase the release of additional nutrients that are normally locked up in bottom sediments (USEPA 2003).

Sedimentation

Clearing of land for agricultural practices such as livestock grazing and crop cultivation typically loosens and smoothes land surfaces increasing soil mobility and vulnerability to surface erosion thereby increasing sedimentation rates in affected streams (Waters 1995; Spence *et al.* 1996). Increased sedimentation can have significant effects on Atlantic salmon habitat by embedding spawning and rearing substrates and increasing turbidity. Increased turbidity reduces light penetration and results in a reduction of aquatic plant communities. Sedimentation from agricultural practices can also increase the inputs of nutrients such as phosphorus, ammonium as well as contaminants such as pesticides and herbicides throughout a watershed. An increase in nutrients can lead to eutrophication

and potential oxygen depletion in surface waters. Exposure of contaminated sediments to anaerobic environments (lacking oxygen) often results in the release of organically bound chemicals (EPA 2003), possibly creating a toxic environment for biotic communities downstream of these agricultural areas.

Fertilizers

Fertilizer runoff can increase nutrient loading in aquatic systems, thereby stimulating the growth of aquatic algae. If nutrient loading due to fertilizer run-off is significant enough, the resulting algal blooms may have numerous detrimental impacts on multiple processes occurring within the affected aquatic ecosystem. Surficial algal blooms that block sunlight can kill submerged aquatic vegetation and large die-offs of algae following blooms can also impair aquatic systems. Loss of submerged vegetation can lead to a loss of habitat for invertebrates and juveniles fishes and the decomposition of dead algae consumes large quantities of oxygen, an impact which, at times, can result in significant oxygen depletion (NMFS and FWS 2005). A reduction in submerged aquatic vegetation and dissolved oxygen (DO) can cause both direct and indirect harm to salmon by affecting not only the physiological function of salmon (e.g., oxygen deprivation) but by impacting prey species and other necessary ecological functions as well.

Pesticides

The Maine Board of Pesticide Control identifies 50 agricultural pesticides that are commonly used in Maine, 11 of which are identified as having high potential for groundwater contamination and another 21 which have been identified as having high potential for surface water contamination (Maine Board of Pesticide Control 2006). The direct effects of agricultural pesticides on Atlantic salmon are most likely to be from pesticides used in blueberry cultivation in Eastern Maine. Exposure of juvenile salmon to a range of sub-lethal concentrations of contaminants may reduce survival of salmon once they reach the ocean (*see section 5.2*).

5.4 Effects of Forestry

Forestry practices have significantly altered Atlantic salmon habitat through harvest, transport and processing of timber. Historically Maine rivers and streams were used for log drives, a practice which included the removal of in-stream obstacles such as boulders and debris, modification of stream channels, construction of flow control dams (*i.e.* flash dams), and establishing push-points along the river where logs were pushed into the river for downstream transport (Fay *et al.* 2006). These practices were designed to improve transport of logs from the upper reaches of the watershed downstream to saw mills or paper mills. Although many of the detrimental practices of past forestry have been greatly reduced, the legacy of large-scale forestry operations continues to affect salmon habitat today (NRC 2003). Three of the most important effects that historical logging practices may still have on salmon habitat today are: (1) the remaining dams that were once used as flow control structures; (2) removal of boulders and physical stream channel alterations; and (3) a reduction in large woody debris (LWD) recruitment.

5.4.1 Historical perspective and significance to Atlantic salmon habitat

Forestry is currently the dominant form of land use throughout the range of the DPS. The history of Maine's forest products output dates back to the 1600's (Maine Forest Products Council 2002) and most forested land in Maine has been subject to one or more cycles of logging. By 1832 the city of Bangor, along the banks of the Penobscot River, was known as the world's largest shipping port for lumber and had more than 300 sawmills which produced more than 8.7 billion board feet of lumber over a period of approximately 50 years (Maine Forest Products Council 2002). In 1900 Maine's annual forest harvest was estimated at approximately two million cord (1.41 billion board feet) and, with the exception of an output decline over the period of the Great Depression (1930's), the total annual output increased to approximately six million cord by 2003 (4.2 billion board feet) (McWilliams *et al.* 2005). According the North East State Foresters Association (NEFA; 2007), Maine forests account for over \$6.5 billion a year to Maine's economy with \$5.3 billion associated with forest-based manufacturing.

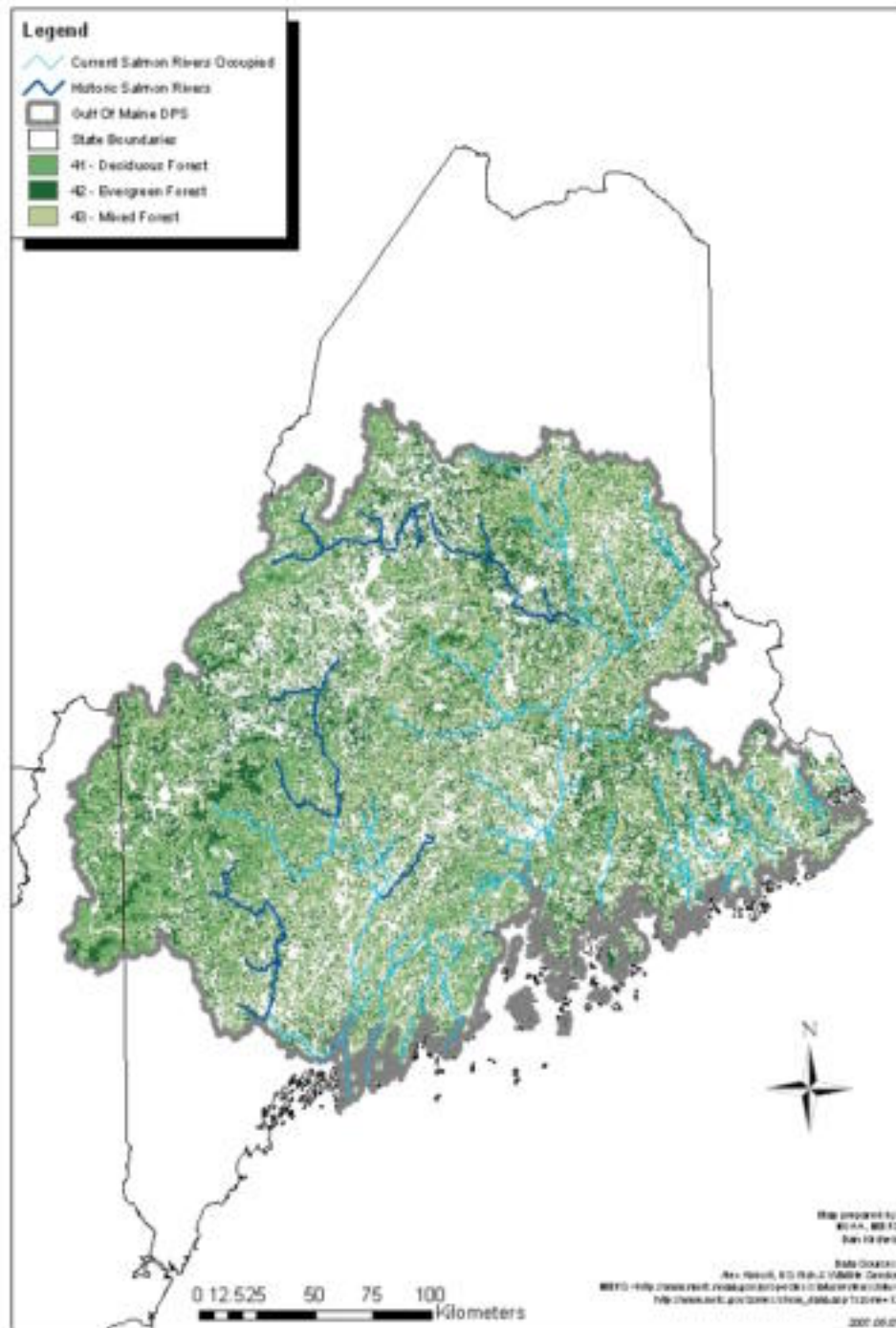


Figure 5.4.1. Forested lands within the GOM DPS (Data source: NLCD 2001)

5.4.2 Forestry today

Today, forestry practices are typically conducted by large corporate operations (McWilliams et al. 2005). Current forestry practices that can affect salmon habitat include road construction and removal of trees for harvest as well as forest thinning and manipulation of understory vegetation (e.g., burning, chemical, or mechanical treatments) to promote growth of certain tree species (Spence *et al.* 1996). Maine law allows for limited cutting within the riparian zone. Modern forestry practices, such as timber harvest, that occur in the riparian zone can decrease shade, decrease supply of large woody debris, and increase erosion and inputs of organic debris. The width of the buffer and the extent that cutting is allowed is based on stream order, the type of water body (e.g., lake, river, coastal) and whether the land is within the jurisdiction of Maine's Department of Environmental Protection or Maine's Land Use Regulatory Commission. In addition to harvest in the riparian zone, timber harvest on hill slopes as well as construction of road crossings for access to timber lands can alter stream-flow through increased surface water runoff from adjacent slopes and increase inputs of coarse and fine sediments. The improper use of culverts during road construction can disrupt natural flow dynamics, obstruct fish passage, and reduce debris and sediment transport.

5.4.3 Hydrology

Timber harvest can significantly affect hydrologic processes. In general, timber removal increases the amount of water that infiltrates the soil and reaches the stream by reducing water losses from evapotranspiration (Spence *et al.* 1996). Soil compaction can decrease infiltration and increase runoff, and roads created for logging can divert and alter water flow. Logging can also influence snow distribution on the ground, and consequently alter the melting rates of the snowpack (Chamberlin *et al.* 1991). Through a combination of these effects, logging can change annual water yield and the magnitude and timing of peak and low flows (Spence *et al.* 1996). For example, Moring and Finlayson (1996) reported that significantly higher stream flows were documented in the East Branch Piscataquis River (tributary to the Penobscot River) in April and May following a year in which a segment of the river was clear-cut up to the stream.

Modern forestry practices may also affect hydrologic process such as the timing of runoff through its effect on transpiration. The difference between transpiration losses in mature and clear-cut areas is greatest during high periods of precipitation and transpiration in the spring and fall. Opening the canopy can also affect runoff by reducing shade covering and increasing wind access, which accelerates snow melt (Chamberlin *et al.* 1991). A study conducted by Hicks *et al.* (1991) examined a 36 year record of stream flows in an Oregon stream, and found that August flows remained abnormally low for a period of eight years following clear cutting and burning compared to streams in an undisturbed watershed.

5.4.4 Water quality

Sedimentation

The increased erosion and runoff caused by forestry practices and road building can increase sedimentation. Compared to other forestry activities, roads are the greatest contributor of sediment on a per area basis (Furniss *et al.* 1991). Contribution of sediments by roads most frequently occurs from mass failure of road beds (Furniss *et al.* 1991). Other forestry practices generally cause surface erosion, creating chronic sediment inputs. Although less dramatic, chronic erosion may be more harmful to stream biota because it occurs over a long time period and involves smaller particles which are more likely to embed in substrates (Spence *et al.* 1996). The combined affect of chronic and mass erosion can cause elevated sediment levels even when a small percentage of a watershed is developed by roads (Montgomery and Buffington 1993).

Pesticides

Forestry practices that utilize pesticides may cause direct or indirect harm to Atlantic salmon within the watershed. The use of pesticides in forestry is substantially less than what is used in agriculture and accounts for less than 1% of the total pesticide use in the USA (Norris *et al.* 1991). Insecticides have been used in commercial forestry to control outbreaks of defoliating insects such as spruce-budworm (Fay *et al.* 2006). Since 1954, over 10 million acres in Northern Maine (roughly half of Maine's total land area) have been treated with chemical and biological insecticides (Flanagan *et al.* 1999). Between 1954 and 1967, dichlorodiphenyltrichloroethane (DDT) was used to treat up to 479,000 acres of affected forest in Northern Maine (Flanagan *et al.* 1999). Between 1970 and 1979, insecticides such as fenitrothion, mexacarbate, carbaryl, as well as the naturally occurring bacterial insecticide bacillus thuringiensis (Bt) were used to treat up to 3.5 million acres in Northern Maine (Flanagan *et al.* 1999). During the last few decades most pesticide use in the state of Maine for forestry purposes has been principally centered around the spruce-budworm outbreak that began in the late 1960's and lasted through the mid-1980's (McWilliams *et al.* 2004).

Herbicides

At present, herbicides are occasionally used in forestry practices to promote the growth of softwoods while discouraging hardwood growth in recently harvested forest lands (Fay *et al.* 2006, Flanagan *et al.* 1999). Triclopyr (trade name 'Garlon') and glyphosphate (trade name 'Rodeo') are the two most commonly used chemical herbicides used today to control emergent vegetation (Flanagan *et al.* 1999). Pesticide and herbicide use in forestry practices are usually infrequent given that harvest frequency ranges between 35 and 80 years depending on whether trees are harvested for pulpwood or for saw logs. During the growth cycle, a forest stand will typically receive no more than two herbicide applications (Fay *et al.* 2006).

5.4.5 Stream temperature

The most direct affect of logging on stream temperature is the reduction in shade provided by riparian vegetation. Removal of riparian vegetation also affects evaporation, convection and advection by altering wind speed and the temperature of surrounding land areas (Beschta *et al.* 1987, 1995). In general, greater affects on stream temperatures are more apparent in smaller streams, however, the magnitude of these effects is dependent on stream size and channel morphology in relation to the quantity of riparian vegetation harvested (Beschta *et al.* 1995). Removal of riparian vegetation can also lead to increased maximum temperatures and increased diel fluctuations in stream temperatures (Beschta *et al.* 1987, 1995). For example, Garman and Moring (1991) conducted water temperature monitoring pre- and post-logging on the East Branch Piscataquis River, near Greenville, Maine. Study sites on the East Branch Piscataquis River were cross referenced to an undisturbed reach upstream from the site. Prior to logging, water temperatures in the disturbed area increased rapidly through May and June reaching a daily maximum of 23.0°C by July resulting in a thermal activity period of 221 days. After logging, the mean daily maximum temperatures were significantly greater ($p < 0.01$) reaching 24.5°C by July with a thermal activity period of 275 days as well as significantly lower daily minimum temperatures and wider diurnal temperature ranges.

5.4.6 Nutrients

Nutrients are directly lost through the removal of trees and other vegetation, and may be indirectly lost through leaching and other processes. However, in the first few years following harvest, more nutrients may be available in stream water because of accelerated decomposition caused by increased sunlight, as the additional slash added to the forest floor (Frazer *et al.* 1990; Beschta *et al.* 1995; Gregory *et al.* 1987). Burning of slash can also temporarily increase nutrients in the system, although nitrogen and other nutrients will volatilize and be lost if the fire is too hot (Gessel and Cole 1973). Nutrient levels may also increase following harvest due to increased water availability, increased runoff, and erosion of unbound nutrients (Frazer *et al.* 1990; Beschta *et al.* 1995; Gregory *et al.* 1987). The temporary influx of nutrients following harvest generally declines after a few years as soils stabilize and re-vegetation begins.

5.4.8 Physical habitat

Forestry practices can affect the physical environment and habitat quality of streams in many ways. These impacts, in turn, can have many potential consequences for Atlantic salmon. Timber harvest and preparation of soil for forestry practices can decrease LWD as well as increase erosion. Removal of LWD and increased erosion can have many harmful affects on salmon habitat by reducing channel complexity, reducing in-stream cover and riffle/pool frequency, decreasing sediment retention and channel stability and reducing availability of microhabitats (Spence *et al.* 1996). Loss of riparian vegetation can also reduce the presence of overhanging banks that are frequently used for cover by salmon (Spence *et al.* 1996).

Logging can create physical obstructions to stream channels through construction of road crossings and input of excessive debris that can create debris jams. The use of culverts for road crossing may degrade both upstream and downstream habitats (Fay *et al.* 2006). Improperly designed or placed culverts (*i.e.* perched culverts) on logging roads can impair habitat connectivity. Perched culverts can delay or block fish passage by increasing water velocities, or creating insufficient water depths and velocities within the culvert.

5.5 Effects of Changing Land-Use Patterns/Development

Maine’s population is expected to grow at a rate of approximately 0.5% per year over the 2004 to 2020 period, and this projected growth rate is consistent with the growth rate over the 1990 to 2004 period (Maine State Planning Office 2005). Most population growth in the state of Maine is expected to be centered around southern and central coastal counties, while northern counties and counties that border Canada are expected to have slower growth rates (Kennebec, Franklin, Somerset, Androscoggin, and Penobscot) or even negative growth rates (Washington, Piscataquis, and Aroostook) (Table 5.5)

Table 5.5. Maine Population Growth by County (Maine State Planning Office 2005)

County	Growth 1990 – 2004	Forecast Growth 2004-2020
York	1.4%	1.2%
Waldo	1.1%	1.0%
Lincoln	1.0%	0.9%
Hancock	0.9%	0.7%
Knox	0.8%	0.6%
Cumberland	0.8%	0.6%
Sagadahoc	0.7%	0.9%
Oxford	0.5%	0.4%
Kennebec	0.3%	0.3%
Somerset	0.2%	0.2%
Franklin	0.1%	0.0%
Androscoggin	0.1%	0.2%
Penobscot	0.1%	0.2%
Washington	-0.4%	-0.5%
Piscataquis	-0.5%	-0.2%
Aroostook	-1.2%	-1.3%

Maine’s younger population, as well as those that move to Maine, are now choosing to live in more urban environments that provide access to public resources, particularly access to higher education, and have greater opportunity for employment (Benson and Sherwood 2004). According to the Maine State Planning Office, the fastest growing towns in Maine are new suburbs that are within 10 to 25 miles from four metropolitan areas in the State of Maine (*i.e.* Bangor, Waterville, Lewiston-Auburn, and Augusta) centered in Penobscot, Androscoggin, and Kennebec Counties (O’Hara and Benson 1997; Benson and Sherwood 2004) (*see* Figure 5.5).

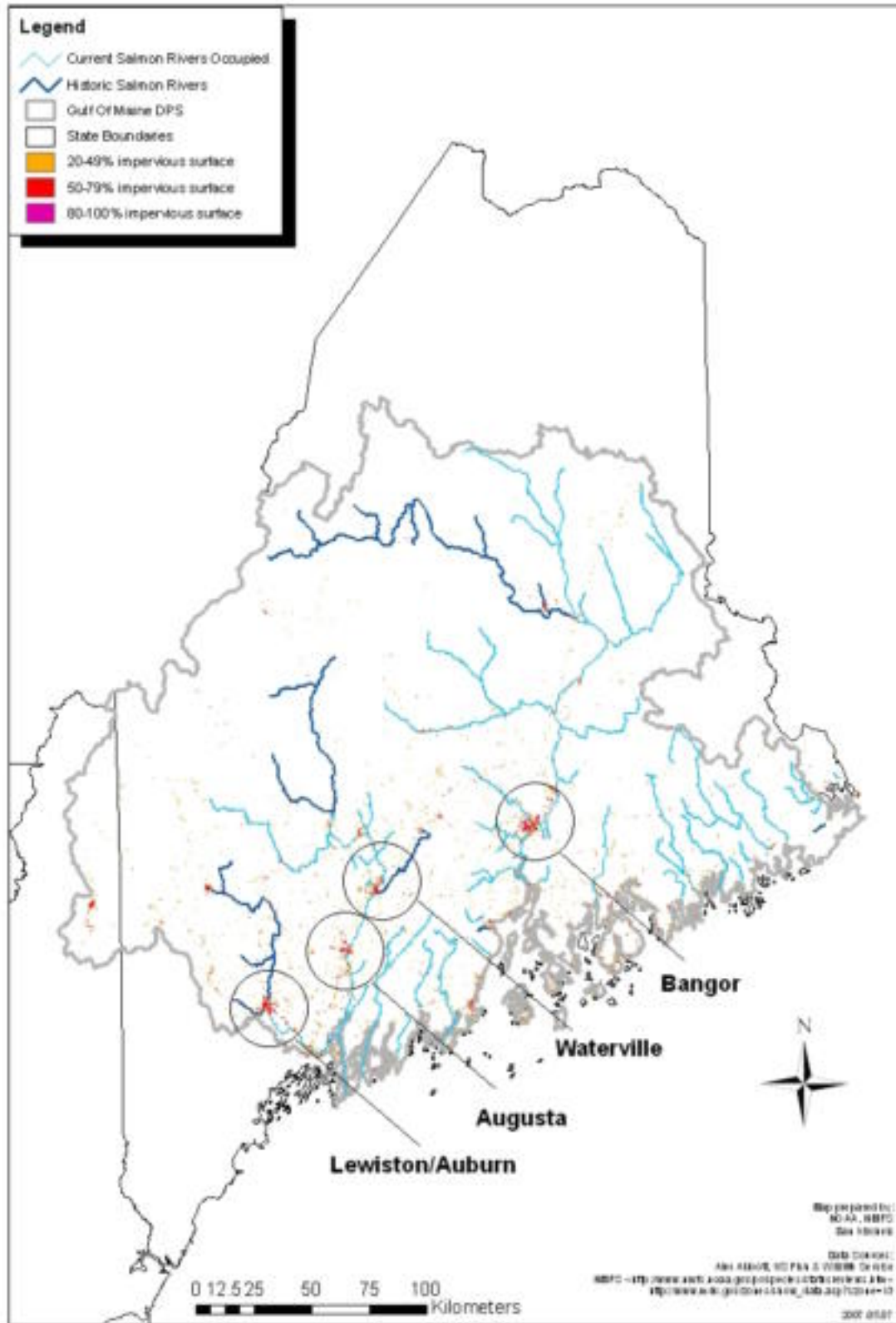


Figure 5.5. Urban areas with greater than 20% impervious surface (Data source: NLCD 2001)

5.5.1 Sediment transport and physical habitat

Changing land-use patterns include a shift from forestry and agriculture to construction of housing, commercial shopping and business centers, and industrial facilities. Increased development and population growth can cause declines in water and habitat quality caused by increases in erosion, reduction of riparian vegetation, increases in sediment deposition, homogenizing of habitat features, and an overall reduction in water quality resulting from point and non-point source pollution. Urbanization and development can affect water bodies by reducing soil infiltration rates and increasing erosion; can remove vegetation that would otherwise intercept rainfall and therefore reduce runoff; and can clear riparian areas decreasing shade and altering nutrient inputs. Additionally, urbanization can lead to alterations in physical habitat as rivers and streams are redirected, channelized, and/or banks are armored to accommodate and protect the development. As areas are cleared and developed, rainfall that normally would be absorbed by soils or plants is redirected as runoff either directly into rivers and streams or diverted through storm drains that also frequently flow into nearby rivers or streams. Surface runoff from developed areas can increase erosion rates, carry pollutants from developed areas, and increase flooding (Morse and Kahl, 2003). As more water is carried downstream during rain events or when stream channels are altered, the result can be an increase in streambed widening or scouring. Streambed widening or scouring can directly reduce the quality and quantity of habitat available to Atlantic salmon. Construction of impervious surfaces can indirectly influence habitat by increasing surface water runoff while concurrently reducing groundwater recharge. A reduction in groundwater recharge can lead to reduced summer baseflows, thereby potentially reducing available aquatic habitat (Morse and Kahl 2003).

5.5.2 Water quality and chemistry

Urbanization is considered the primary factor affecting the chemical quality and health of aquatic ecosystems in streams of the New England Coastal Basins (Robinson *et al.* 2004). Runoff can increase water temperatures as rainwater is heated while passing over rooftops and paved surfaces before entering nearby rivers and streams (Morse and Kahl 2003). Surface water runoff from developed areas can also carry potentially toxic pollutants including fertilizers, pesticides, oil and gasoline, and heavy metals into aquatic ecosystems (Morse and Kahl 2003). Rivers that drain highly urbanized watersheds may contain concentrations of trace elements such as arsenic, chromium, copper, cadmium, lead, mercury, and zinc (Robinson *et al.* 1999, 2001). Runoff from highly urbanized areas can also contain volatile organic compounds (VOC's) from household cleaners (e.g. the disinfection by-product chloroform) and fossil fuels (e.g., gasoline additives methyl tert-butyl ether (MTBE) and trichloroethene (TCE)) (Robinson *et al.* 1999, 2001). The addition of organic materials to aquatic environments increases biological oxygen demands, while the heavy metals, pesticides, polychlorinated biphenyls (PCB's) and polycyclic aromatic hydrocarbons (PAH's) have both lethal and sublethal affects to Atlantic salmon. Possible sub-lethal affects include reduced growth, decreased reproductive success, altered behavior and reduced resistance to stress (Beschta *et al.* 1995).

Municipal Discharges

Municipal water discharges, generically termed outfalls, transport water separated from biosolids (wastewater outfalls), and stormwater run-off from streets and homes (stormwater outfalls) into aquatic environments. Wastewater outfalls are cylinders constructed of concrete and steel, and are found at wastewater treatment plants (Williams and Thom 2001). Stormwater outfalls can consist of one single pipe laid at ground level draining a single family's property, or can be an amalgamation of concrete and steel pipes handling both storm run-off and sewage (Williams and Thom 2001). With the exception of the small single pipe stormwater drain, outfalls are positioned via excavation of the site and construction of the pipe (Williams and Thom 2001). The excavation and construction of the stormwater and wastewater drainages can adversely affect the biological and ecological processes within an area (Williams and Thom 2001). Wastewater outfalls may transport their refuse directly into an aquatic environment (Williams and Thom 2001). Stormwater and wastewater discharges into aquatic environments can result in altered water temperatures, changes in turbidity, increases in inorganic nutrients, increases in organic matter, increases in biological contaminants (e.g., coliform bacteria, and viruses), and increases in toxic chemicals (e.g., heavy metals) (Williams and Thom 2001).

5.5.3 *Stream biota*

Studies from the Northwest indicate that urban pollution may have insidious effects on anadromous salmonids. These studies show that salmonids migrating through polluted urban waters bioaccumulate Polychlorinated Biphenyls (PCB's) and Polycyclic Aromatic Hydrocarbons (PAH's), causing the fish to exhibit suppressed immune function and impaired growth (Casillas *et al.* 1993; Arkoosh *et al.* 1994). Such exposure of migrating fish can be particularly harmful because it occurs during the physiologically stressful period of smoltification (Spence *et al.* 1996).

Robinson *et al.* (2004) reported that stream habitats in the New England coastal basins start to degrade when as little as 3% of the land cover in a watershed is urban and is considered to be fully degraded when urban areas cover about 20% of the watershed areas. Robinson *et al.* (2004) also states that the quality of invertebrate communities in streams declines with increasing urban intensity. In streams with 2 percent urban land, the number of Ephemeroptera + Plecoptera + Trichoptera (EPT) taxa contained more than 20 species per stratum where as highly urbanized lands (as much as 68% developed) contained as few as 4 EPT species per stratum. Robinson *et al.* (2004) further states that the occurrence of fish that prefer fast-flowing waters and the abundance of cyprinidae decline with increasing urbanization.

Kemp and Spotila (1997) reported that fish communities and benthic macroinvertebrate communities in an urbanized section of stream in Pennsylvania were dominated by pollution tolerant species including creek chub (*Semotilus atromaculatus*), green sunfish (*Lepomis cyanellus*), and *Isopoda*. Brown trout (*Salmo trutta*), which were a major component to the fish community in undeveloped upstream portions of the watershed, were absent from urbanized areas.

Morse (2001) looked at the physical, chemical and biological characteristics of 20 streams in Maine subject to varying intensities of urban development. He found that in streams where the catchment had less than 6% impervious surfaces there were higher levels of Ephemeroptera+Plecoptera+Trichoptera (EPT) taxonomic richness compared to streams that had greater than 6% impervious surfaces. Additionally, in areas with >6% impervious surfaces, invertebrate communities were largely composed of pollution-tolerant Trichoptera, Diptera, and Oligochaeta, whereas in areas with less than 6% impervious surfaces were found to be predominately species that are considered to be only moderately sensitive to pollution and anthropogenic stresses. Those streams below 6% impervious surfaces contained invertebrate communities with average total richness of 33 taxa in the fall and 31 taxa in the spring, and an average EPT richness of 15 taxa in the fall and 13 taxa in the spring. While streams located in catchments with 6% to 27% impervious surfaces had an average total richness of less than 18 taxa and average EPT richness of less than 6 taxa.

5.6 Effects of roads and road crossings

Roads, which are typically built in association with logging, agriculture, and development, are often negatively correlated with the ecological health of an area (Trombulak and Frissell 2000). Road networks modify the hydrologic and sediment transport regimes of watersheds by accelerating erosion and sediment loading, altering channel morphology and accelerating runoff (Furniss *et al.* 1991). In addition, the construction of roads near streams can prevent natural channel adjustments, and urban roads may increase runoff of pollutants (Spence *et al.* 1996).

The use of culverts and bridges during road construction can negatively influence aquatic ecosystems and impair habitat connectivity. Impaired habitat connectivity limits the accessibility of habitat to juvenile and adult salmon, as well as other fish and aquatic organisms (Furniss *et al.* 1991). Culverts, if they are not properly installed or maintained, can partition a watershed and make reaches inaccessible to migratory fish while simultaneously preventing upstream movement of resident fish and invertebrates. Conditions induced by culverts that block fish passage include high water velocities through the culvert over extended distances without adequate resting areas; water depth within the culvert that is too shallow for fish to swim; and culverts that are perched or hanging and exclude fish from entering the culvert (Furniss *et al.* 1991).

Alternatively, bridges, which are preferred to culverts (Furniss *et al.* 1991), may also induce negative ecological impacts. Poorly designed bridges, like culverts, can alter sediment transport, natural alluvial adjustments, and downstream transport of organic material, particularly large woody debris. Despite the fact that bridges are the preferable choice in regards to minimizing habitat impacts, road crossings over smaller streams are often composed of corrugated metal culverts in order to reduce costs.

Throughout the range of the GOM DPS, it is common to find road crossings that are poorly designed or maintained. A survey conducted in the Piscataquis River watershed by Baker (2004) found a total of 184, 56% of which did not meet the recommended width

requirements and approximately 90% of which lacked any substrate and were therefore an impediment to fish passage. Of the 84 culverts surveyed, 17 were red-flagged as barriers to all fish and salamanders and another 15 culvert were determined to be a barrier to all fish and salamanders except adult salmonids.

5.6.1 Sedimentation

Roads are a major source of anthropogenic sedimentation in a watershed and often contribute more sediment per unit area than all other land management activities (Gibbons and Salo 1973). Improper construction, poor placement of road fill, inadequate road maintenance, insufficient culvert size, steep associated hill-slope gradients, inadequate placement of excess material, and poor road locations can all contribute to mass movements of sediments (Furniss *et al.* 1991). The use of restrictive culverts (*i.e.* culverts that are too small and therefore concentrate flow) can lead to increased stream channel scour, streambank erosion and undermining of the culvert itself which can lead to catastrophic failure of the structure causing extensive sediment loading downstream (Furniss *et al.* 1991). Mass movement of sediments may cause diminished habitat complexity and stream channel alteration. Sediment loading can increase embeddedness of spawning and incubation substrates rendering spawning areas unsuitable (Furniss *et al.* 1991); limiting food availability to juveniles by reducing macroinvertebrate habitat (Cordone and Kelley 1961); and reducing physical space available for rearing (Furniss *et al.* 1991). Excessive sedimentation can cause direct mortality by smothering eggs and fry (Phillips *et al.* 1975; Furniss *et al.* 1991). High turbidity associated with excessive erosion can disrupt fish behavior and reduce growth (Murphy 1995). Exposure to total suspended solids (TSS) of 10mg/L or a single day exposure to TSS greater than 50mg/L can cause moderate stress to juvenile and adult salmonids (Newcomb and Jensen 1996).

5.6.2 Physical structure

Stream channels are in a constant state of adjustment, and the construction of roads and road crossings that constrict the stream channel can prevent natural stream channel adjustments from occurring (Furniss *et al.* 1991). Stream channel adjustments can influence the geometry of the stream channel and will cause the stream to adjust by altering its geometry upstream and/or downstream of the constriction (Furniss *et al.* 1991). Changes in geometry can include changes in channel bed form, channel bed armor, channel width, channel pattern or alignment, and longitudinal profile (Heede 1980); any change in stream geometry may degrade or destroy salmon habitat.

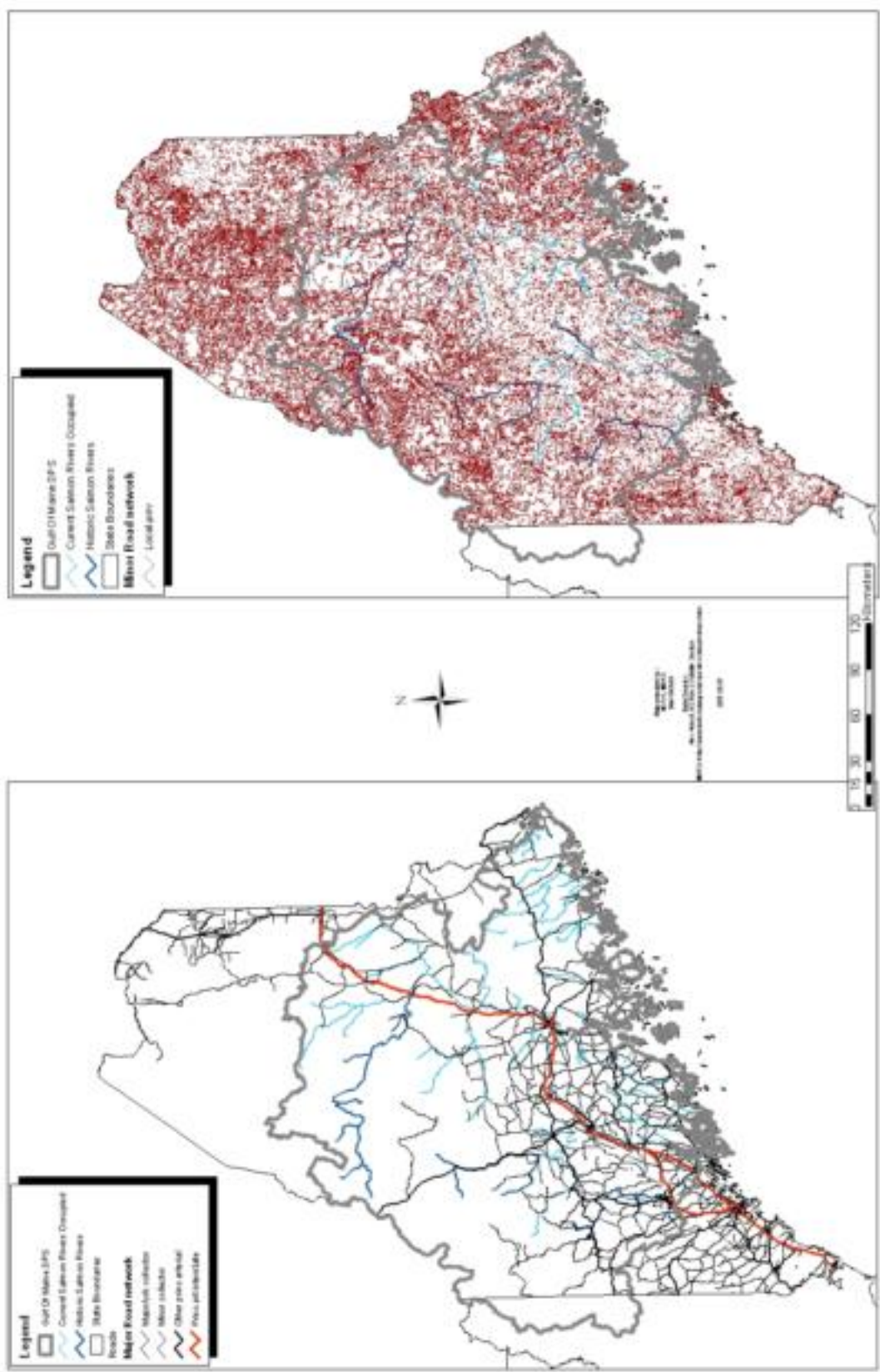


Figure 5.6. Major and minor road network throughout Maine

5.6.3 Water quality and stream flow

Maintenance and use of roads increases the amount of many pollutants in the stream environment. Pollutants associated with roads and road crossings include heavy metals, salt, organic molecules, and nutrients (Trombulak and Frissell 2000). Roads also facilitate the entrance of other pollutants into waterways by decreasing surface permeability and increasing runoff. Urban and suburban areas, logging areas, agricultural land, and industrial areas produce excess nutrients, petroleum products, herbicides and pesticides, toxic wastes and many other pollutants which can flow into waterways through roads and their drainage systems.

The removal of vegetation and loss of permeable ground associated with bridge and culvert construction increases and re-routes run-off down drainage ditches directly to the stream. Increased run-off can cause increased peak flows and bank scouring, (Sidle *et al.* 1985) and may cause increased channel width (Dose and Roper 1994). Culverts that restrict flows can increase velocities through the pipe resulting in increased streambed scour. Restrictive culverts, even when set properly, can become perched over time as increased velocities cause excessive local scour downstream of the pipe.

5.6.4 Fish passage

Culvert or bridge openings narrower than the natural river channel increase water velocity and can delay or block fish passage. Improperly placed or designed culverts impair fish passage with hanging outfalls, increased water velocities, or insufficient water depth or velocity within the culvert (Fay *et al.* 2006).

5.7 Effects of mining

Sand, gravel, cement, and some varieties of stone (e.g., slate and granite) and clay are mined extensively throughout Maine. Mining of these materials in Maine occurs to the extent that Maine is largely self-sufficient for these commodities (Lepage *et al.* 1991).

Additionally, Maine's crystalline rocks are potential hosts to an array of metals including copper, zinc, lead, nickel, molybdenum, tin, tungsten, cobalt, beryllium, uranium, manganese, iron, gold and silver (Lepage *et al.* 1991). Maine has a fairly long history of sporadic mining for metals that dates back as far as the early 1800's when mines were operated for iron which was shipped to Boston, and lead that was mined near Lubec. The most recent metallic mine was the old Harborside Mine operated by Callahan Mining Cooperation from 1968 through 1972 set up to extract copper and zinc concentrates from ore; and the Black Hawk Mine in Blue Hill that operated from 1972 through 1977 that extracted concentrates of zinc, copper and lead (Lepage *et al.* 1991). Currently there are no metal mines in Maine, though exploration has continued to assess Maine's potential for metal mining. Factors that could promote mining for metals include the search for alternative energy sources, uncertainties surrounding mineral supplies from foreign countries and price increases of particular metals (Lepage *et al.* 1991).

There are only two active, though limited, peat mining operations in Maine, both of which are located in Washington County (USGS 2006; Corliss e-mail communication). Although there is currently no direct evidence that peat mining in other countries (*i.e.*

Ireland, Norway) has affected Atlantic salmon, studies have shown that peat mining can affect water quality, wetlands, aquatic resources and sediment load (Maine Atlantic Salmon Task Force, 1997).

5.7.1 Habitat and sedimentation

Sand and gravel mining can occur in the form of gravel pits and in some cases can involve dredging of streambeds. Sand and gravel mining in or adjacent to streams can increase fine and coarse particle deposition and elevate turbidity from suspended sediments (Waters 1995) as mining operations can redirect surface flows and accelerate sediment delivery to streams and lakes (Nelson *et al.* 1991).

5.7.2 Water chemistry

One potential effect of peat mining on Atlantic salmon habitat is that runoff from peat mining operations may have historically exacerbated depressed pH in DPS rivers (NMFS and FWS 1999). However, if declines in pH are attributed to increased DOC content, it may have varying levels of impact to resident aquatic organisms downstream of the mining areas.

5.7.3 Atlantic salmon physiology

Many metals occur naturally in rivers and streams and in trace concentrations are considered essential for proper physiological development of fish (Nelson *et al.* 1991). The process of mining for metals can introduce toxic metals into streams as acid stimulation mobilizes metal ions from metalliferous minerals (Nelson *et al.* 1991). The most frequent metals that are released into streams and may be toxic to salmon depending on their concentration include arsenic (As), cadmium (Cd), chromium (Cr), cobalt (Co), copper (Cu), iron (Fe), lead (Pb), manganese (Mn), mercury (Hg), nickel (Ni), and zinc (Zn) (Nelson *et al.* 1991). Dissolved copper is known to affect a variety of biological endpoints in fish (e.g., survival, growth, behavior, osmoregulation, sensory system, and others (reviewed in Eisler 1998)). Laboratory exposure of 2.4 micrograms/L dissolved copper in water with hardness 20mg/L resulted in avoidance behavior by juvenile Atlantic salmon and 20 micrograms/L dissolved copper in water with a hardness of 20mg/L resulted in interrupted spawning migrations in the wild (Sprague *et al.* 1965). A combined effect of copper-zinc may result in a complete block of migration at 0.8 toxic units (Saunders and Sprague 1964).

5.8 Effects of hatcheries and stocking

Use of hatcheries may be essential to rebuild Atlantic salmon populations, however, without proper adherence to genetic, evolutionary, and ecological principles, the use of hatcheries could have adverse consequences for naturally reproducing fish that may undermine other rehabilitation efforts. Stocking of Atlantic salmon that are river specific, non river specific, or a combination of both, is taking place in many DPS rivers and supportive breeding through adult stocking of captive-reared brood stock is also occurring in small numbers in most DPS rivers (NRC 2003). In addition, smallmouth bass and chain pickerel have been introduced throughout a significant portion of the DPS and are important non-native predators of juvenile salmon (Fay *et al.* 2006). Similar to chain pickerel, juvenile smallmouth bass, along with a host of other native and non-native

fish, may also prey on and compete with Atlantic salmon in freshwater. The competitive interactions between Atlantic salmon and other non-salmonids are not well understood (NMFS and FWS 2005).

5.8.1 Atlantic salmon

Although sanctioned state and federal re-stocking hatchery programs conform to previously established best management practices (BMPs) and are not a large threat to wild populations, there are private hatcheries that produce eggs, from non-indigenous Atlantic salmon strains, for use in the aquaculture industry. The effects of inadvertent introductions from these hatcheries are similar to those caused by aquaculture escapes. Additionally, the carrying capacity of streams is limited for certain salmon life stages (White 1995), and the introduction of captive-reared salmon may increase competition enough to limit populations of wild salmon.

Entry of escaped farmed salmon into freshwater may influence natural migration and spawning, as well as mating selectivity and breeding success of Atlantic salmon. In addition, farmed salmon and their offspring may have competitive advantages, at some or all life stages (Jonsson 1997; Gross 1998; NMFS/FWS 2005) that allow them to displace wild salmon. Competition may occur between hatchery-reared and wild adults for redd habitat, however, escaped farmed salmon have been documented to spawn later than wild salmon which increases the potential of farmed fish to destroy nests by earlier spawning wild females (Webb *et al.* 1991). Additionally, there has been little evidence of farm salmon directly disrupting wild salmon spawning, and little indication that competition affects fertilization rates or female performance (Fleming *et al.* 1996, 2000; Garant *et al.* 2003). However, competition between hatchery-reared and wild fish has not been well researched and potential interactions are not well understood (Fay *et al.* 2006).

5.8.2 Species interactions

Non-native species introductions affect the biological habitat features of Atlantic salmon by altering predator-prey interactions and increasing competition for space and food. Salmon are preyed on by, and in competition with, many species of fish. Although interspecific competition and predation are natural parts of salmon evolution and ecology, these interactions are now more harmful because salmon populations are severely depleted. Additionally the problem of interspecific competition is compounded by the legal and illegal introductions of non-native fish species in freshwaters throughout the range of the DPS (Fay *et al.* 2006). Atlantic salmon have not evolved in the presence of non-native species, therefore, non-native species are often more harmful to Atlantic salmon than native predators and competitors.

5.9 Effects of anthropogenic acidification

Generally speaking, the greatest concern with anthropogenic acidification for Atlantic salmon is the associated reduction in pH of freshwater environments. The direct effects of anthropogenic acidification (*i.e.* reduced pH) on fishes includes mortality, reproductive failure, reduced growth rates, skeletal deformities, and increased uptake of heavy metals (Haines 1981). By effectively lowering pH, anthropogenic acidification can lead to numerous changes in water chemistry that have the potential to greatly influence Atlantic

salmon in the freshwater environment. Additionally, in the marine environment, Atlantic salmon growth, behavior, and survival may be significantly negatively influenced by anthropogenic acidification events experienced during freshwater residence.

Anthropogenic acidification largely occurs as a result of acid precipitation. Acid precipitation is derived largely from the combustion of fossil fuels and is most often associated with coal, oil and gas utility plants, automobiles, and factory smokestacks (<http://www.maine.gov/dep/air/acidrain>), and frequently occurs in association with rain, snow, sleet, hail or fog. Anthropogenic acidification may also occur in the form of dust particles that settle out of the atmosphere (<http://www.maine.gov/dep/air/acidrain>).

Throughout the Northeast and in Maine specifically, the effects of anthropogenic acidification on Atlantic salmon are of concern. The potential for negative impacts due to acidification is typically dictated by the geology of that effected area. In Maine, the bedrock geology is largely divided by a line running from the Penobscot River near Winterport northeast towards Topsfield identified as the Norumbega Fault. North and West of this line rocks are largely derived of former marine sediments and rocks containing a fraction of carbonate whereas rocks south and east of this line are largely derived from volcanic and more recent intrusive igneous rocks and therefore have even less carbonate. Both types of bedrock are considered to have low acid neutralizing capacity (ANC) (Johnson and Kahl 2005) making salmon rivers in Maine particularly vulnerable to anthropogenic acidification (Omernik and Kinney 1985). In addition to natural vulnerability to anthropogenic acidification, the northeast has continually been exposed to anthropogenic acid deposition further reducing the regions ANC. Recent measures of acid deposition (figure 5.9) show the pH of precipitation throughout the northeast to be moderately acidic relative to the greater United States.

The geochemistry, geomorphology, and hydrodynamics of a watershed determine the degree to which acidic deposition affects water chemistry and the water and soils ability to withstand acidification (Haines 1981). Decreases in acid neutralizing capacity (ANC) result in an increased vulnerability to acidification because ANC is a measure of a systems (soil or water) ability to neutralize inputs of strong acids (Driscoll *et al.* 2001). As a result, increased acid deposition in the presence of low ANC has the potential to greatly influence a stream's water chemistry. In addition to acid deposition, changes in forestry and land management practices, addition of road salts, addition of fertilizers, pesticides and other chemicals and even changes in fish community structures (e.g. reduced diadromous fish abundance) may alter the chemical nature of freshwater rivers and streams which could in turn effect their ANC and the overall influence of anthropogenic acidification on water chemistry.

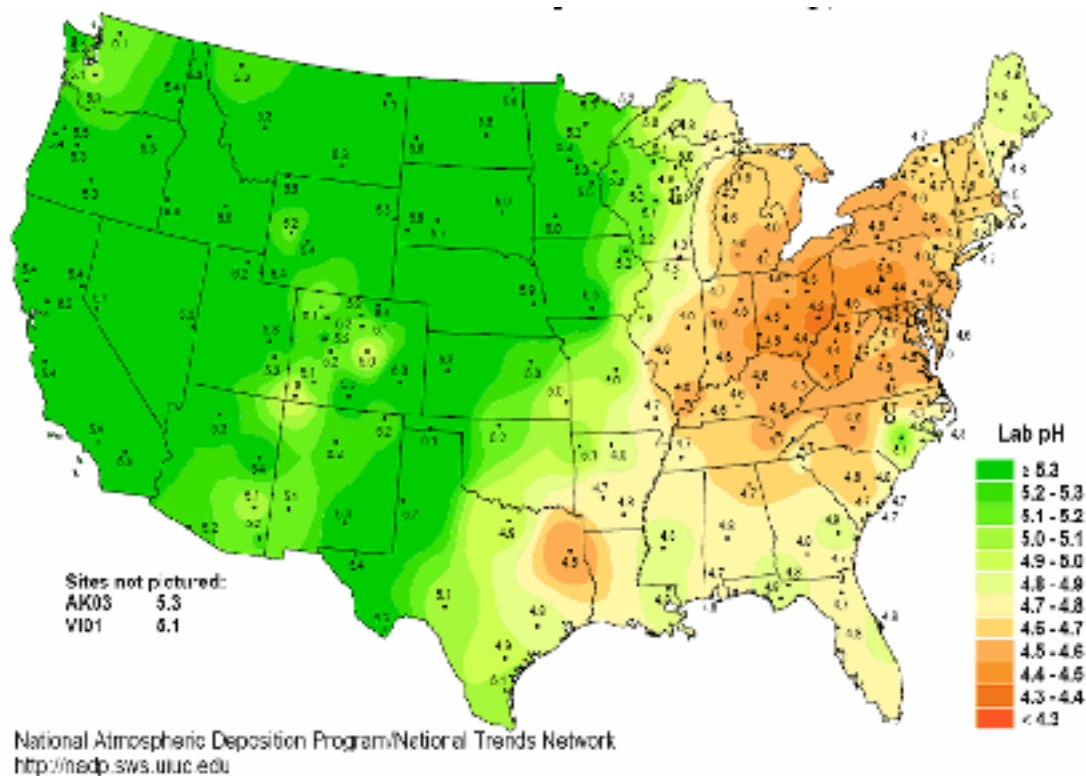


Figure 5.9 Hydrogen ion concentration as pH from measurements made at the Central Analytical Laboratory, 2005

5.9.1 Water chemistry

The earliest evidence of the affects of acidic deposition on aquatic ecosystems was the reported correlation between low pH and declines of Atlantic salmon in Norwegian rivers in the 1920's (Jensen and Snekvik 1972; Wright *et al.* 1976). Numerous studies have shown that declines in pH are capable of impairing the development of juvenile Atlantic salmon (Staurnes *et al.* 1995; Brodeur *et al.* 2001). Exposure of low pH water can cause edema between the outer gill lamellar cells and remaining tissue as well as erosion of lamellae and swelling of filaments (McKenna and Duerr 1976). Additionally, acute mortality of Atlantic salmon and brown trout have been recorded in Norway when pH ranged from 3.9 to 4.6 (Jensen and Snekvik 1972; Leivestad and Muniz 1976; Leivestad *et al.* 1976; Wright *et al.* 1976).

Low pH, particularly levels below 6.0, impairs the seawater tolerance of Atlantic salmon smolts (Staurnes *et al.* 1993; Staurnes *et al.* 1996; Kroglund and Staurnes 1999). When combined with increased metal ions such as aluminum, low pH has been shown to produce a synergistic negative effect, dramatically reducing the seawater tolerance of salmon smolts beyond that of just low pH (Staurnes *et al.* 1993). Aluminum, the third most abundant element in the earth's crust, in high concentrations is recognized as highly toxic to aquatic organisms (Rosseland *et al.* 1990). The parr-smolt transformation of Atlantic salmon is particularly sensitive to such conditions as evidenced by gill damage, respiratory and osmoregulatory disruption, and reduced seawater tolerance observed in both field and laboratory studies (Haines 1981; Saunders *et al.* 1983b; Lacroix and

Townsend 1987; Brown *et al.* 1990; Staurnes *et al.* 1995, 1996; Jagoe and Haines 1997; Magee *et al.* 2001; Magee *et al.* 2003). Smolts exposed for as little as 12 hours to low pH and high aluminum in the freshwater environment can degrade or eliminate the development of Na⁺, K⁺ - ATPase activity and salinity tolerance (Saunders *et al.* 1983b; Staurnes *et al.* 1996). In addition to reducing osmoregulatory abilities, this combination of low pH and high aluminum may also cause significant swelling and fusion of secondary lamellae in gills of Atlantic salmon (Smith and Haines 1995) and, at times, up to 100% mortality of smolts (Kroglund and Staurnes 1999). Sensitivity to the pH/aluminum interaction increases as smolting progresses (Staurnes *et al.* 1993) and exposure to these conditions may impair physiological functions in just a few hours, leading to a reduction in seawater readiness and overall survival of migrating Atlantic salmon smolts (Staurnes *et al.* 1996).

As previously mentioned, the geology surrounding most of Maine's salmon rivers typically has very low ANC, however, Maine's rivers are not currently considered to be chronically acidified (Haines *et al.* 1990). Haines *et al.* (1990) conducted a study on six small streams in Eastern Maine to investigate the influences of precipitation chemistry on stream chemistry and on resident fish communities. In general, pH is lower in headwater streams and at higher elevations (Schofield 1981). Research also suggests that the ANC of eastern Maine rivers is decreasing (Fay *et al.* 2006).

5.10 Effects of global climate change

Global climate change can affect all aspects of the salmon's life history as entire ecosystems can shift rapidly (compared to evolutionary timescales) from one state to another, altering habitat features through increases in sea surface temperatures (IPCC 2001); changes in frequency of seasonal cycles of phytoplankton, zooplankton and fish populations in the marine environment (Greene and Pershing 2007); changes in freshwater hydrologic regimes; and altering the timing and frequency of river ice flows. All of these factors can significantly alter the ecosystem in which salmon have become adapted by effecting environmental cues that stimulate migration, spawning and feeding activities. These changes can also alter predator/prey assemblages by decreasing qualitative habitat features that benefit salmon while concurrently increasing habitat features that benefit predators and competitors.

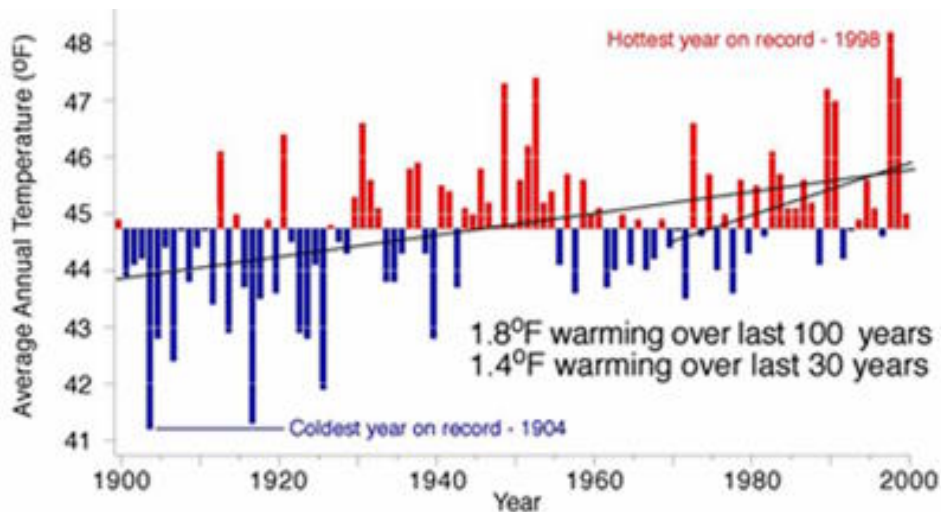


Figure 5.10. Average annual temperature trend in the Northeast United States based upon temperature records collected at 56 stations throughout the region (Graph acquired from Clean Air – Cool Planet and C. Wake, 2005).

5.10.1 Water temperature

Along coastal rivers within the GOM DPS, records extending back to the early 1900's indicate that spring runoff has become earlier, fall ice-on is later, and there are fewer days of total winter ice on Maine rivers (Dudley and Hodgkins 2002). In support of these observations, a combination of land-surface and sea surface air temperature data shows an overall increasing trend in annual air temperatures for New England between the period of 1901 to 2000, with the greatest seasonal warming rates occurring in the winter months December, January and February as indicated by a period of record extending from 1976 to 2000 (IPCC 2001).

5.10.2 Atlantic salmon

Thermal changes of just a few degrees celsius can critically impact biological functions of salmon including: metabolism (McCarthy and Houlihan 1997; Somero and Hofmann 1997; Reid *et al.* 1998), reproductive performance (Van Der Kraak and Pankhurst 1997), response to contaminants (Reid *et al.* 1997) and smolt development (McCormick *et al.* 1998). Unnatural changes in water temperatures may also affect the growth, survival and migration timing of Atlantic salmon in freshwater, the survival and timing of migrating smolts in the estuarine environment, and the survival of juveniles soon after entering the marine environment (NRC 2003).

For migrating smolts, the interrelatedness of water temperature and photoperiod may be extremely important to consider and it has been suggested that GOM DPS salmon may be especially sensitive to climate change because they are at the southern limit of the Atlantic salmon's range (Fay *et al.* 2006). One of the concerns with climate change is the rate at which water temperatures increase could conceivably regulate the window of opportunity in which smolts can successfully transition from freshwater to saltwater.

McCormick *et al.* (1998) suggested that smolts experiencing delays in migration, such as those that occur at dams, may have lower survival rates if they are unable to reach saltwater within the migration window. One possible explanation for this reduced survivorship is that a shortened migration window due to increased temperatures could conceivably result in increased predation pressure as more smolts are forced to migrate over a shorter period of time. Juanes *et al.* (2004) examined migration timing data from the Connecticut River drainage and from drainages in Maine and Canada and found a shift towards earlier peak migration dates across systems, correlating with long term changes in temperature and flow that may represent a response to global climate change.

In addition to reduced freshwater survival as a result of increases water temperatures, increases in sea surface temperatures may also reduce marine survival of Atlantic salmon. A study by Friedland *et al.* (2003b) indicated that North Atlantic salmon survival may be negatively correlated with sea-surface temperature. Unfortunately, the causal mechanisms of the relationship between surface temperatures and migration timing remain elusive (NRC 2003) and although physiological changes are somewhat predictable on an individual level, it is currently not possible to predict interactions between individuals, species, or populations within their environments (NMFS/FWS 2005). Changes to ocean conditions could, however, affect the amount and kinds of prey available to Atlantic salmon, and the degree to which they are preyed upon (NRC 2003).

5.11 Effects of aquaculture

The influence of aquaculture on Atlantic salmon is most frequently related to the interactions between wild fish and escapees from aquaculture facilities. Most escapes of farm salmon occur in the marine environment and involve smolts, post-smolts and adults. Large escapes of aquaculture fish have occurred in Maine and Canada and escaped farm salmon are known to enter Maine rivers. Escapes have been caused by storms, cage failure, anchor failure, human error, vandalism, and predator attacks (NMFS/FWS 2005). Although there is little direct information about the effects of net-pen salmon aquaculture on wild Maine salmon (NRC 2003), potentially harmful interactions between wild and farmed salmon can be divided into ecological and genetic interactions. Ecological interactions can result in alterations in disease transmission, and changes to competition and predation pressures, whereas genetic interactions can modify the timing of important life history events and thereby alter selection pressures and fitness. These interactions are not mutually exclusive, and the effects of each may compound and influence the effects of the other.

5.11.1 Atlantic salmon

Escaped farm spawners can potentially influence natural migration and spawning, and behavioral interactions can affect mating selectivity and interbreeding (NRC 2003). There is little evidence that farm salmon directly impair spawning (Fleming *et al.* 1996, 2000). There is also little indication that the aquaculture escapees affect fertilization rates or performance of wild females. Therefore, the most likely negative interactions between wild and aquaculture salmon are due to increases in disease transmission rates as well as increased competition from aquaculture escapees.

Behavior

During the breeding season a primary threat to wild salmon is the destruction of nests by later spawning aquaculture females (Lura and Saegrov 1991; Webb *et al.* 1991). In addition to competition for spawning habitat, competitive interactions that occur during the fry and parr life-stages can be altered by conspecific organisms, such as aquaculture salmon. Aquaculture fish are selected for fast, early growth, and therefore often outgrow their wild counterparts (Gjedrem *et al.* 1991; Glebe 1998), and the presence of aquaculture fish in the wild can lead to a competitive displacement of wild salmon (Fleming *et al.* 2000; McGinnity *et al.* 1997, 2003). For example, McGinnity *et al.* (2003) examined the lifetime successes between wild, hybrid and farmed salmon and found that although farmed salmon and hybrids showed reduced survival compared to that of wild salmon, the farmed and hybrid salmon grew faster and the farmed and hybrid parr displaced wild parr. McGinnity *et al.* (2003) also found that in a river that naturally produces 1 sea-winter (1SW) wild Atlantic salmon, the farmed and hybrid Salmon produced proportionally more 2SW salmon with lower overall survival rates. As a result, McGinnity *et al.* (2003) concluded that the interactions of farm fish with wild salmon resulted in lowered fitness as repeated escapes can cause cumulative fitness depression and potentially result in an extinction vortex in vulnerable populations. Lacroix *et al.* (2004, 2005) found that the presence of salmon farms along the migration route of post-smolts from Passamaquoddy Bay did not delay migration, but wild salmon losses did occur near farms where potential predators were abundant.

Predator-prey relationships

Hatcheries and aquaculture facilities in coastal areas, including estuaries, increase predation on wild salmon by attracting predators with large concentrations of fish (Montevecchi and Cairns 2002b; Lacroix *et al.* 2004; Nelson *et al.* 2006; Whoriskey *et al.* 2006). Nelson *et al.* (2006) found that rates of seal predation in aquaculture facilities is correlated with higher concentrations of salmon farms, and is greater at farms close to seal haul-outs. Seal predation was, however, reduced by regular maintenance and replacement of netting.

Disease and Parasites

Marine salmon pens may have other deleterious effects on salmon health and immune response through the buildup of waste material (Ackefors and Enell 1994) which can lead to sediment enrichment (Johnsen *et al.* 1993) and anoxia (Black *et al.* 1996). Such environmental effects may promote the development of invertebrates which serve as hosts for certain diseases (Bakke and Harris 1998).

Two major disease problems for East Coast North America are sea lice and infectious salmon anemia (ISA), used here as examples of pathogens that may be present at marine aquaculture facilities. Both sea lice and ISA are transmitted through water and the intensive culture practices that are used in salmon farming have resulted in epidemics.

Mortality due to salmon lice infection is believed to be a major factor regulating stock size in many western Norwegian salmon stocks in most years from 1998 – 2002 (Holst *et al.* 2003). Controlled experiments suggest a mortal level of 11 adult lice on wild post-

smolts, which is in accordance with oceanic observations (Holst *et al.* 2003; Holm *et al.* 2000). Holst *et al.* (2003) found that the hydrographic features of the specific year and fjord appear to be a major factor governing the level of sea lice infection, with more freshwater unfavorable for the sea lice.

Many diseases can be passed from aquaculture facilities located in estuaries, bays and other coastal areas to wild fish migrating to or from the ocean. Epidemics of furunculosis in the salmon farming industry can pose threats to wild salmon, especially where wild populations are depressed (Gross 1998; McGinnity *et al.* 2003) and the risk of ISA infection in marine aquaculture facilities is greater when sites are closer together (< 5km apart), although this risk is reduced when waste water is properly disinfected (Jarp and Karlsen 1997). However, the most serious risks of epizootics are from new diseases linked to movements of live fish for farming or restocking (McVicar 1998; Bakke and Harris 1998).

5.11.2 Habitat

The location of the aquaculture facility may directly impact salmon migration by physically blocking migration routes and impairing the homing success of wild salmon returning to their natal rivers. The high concentrations of fish in aquaculture facilities may also attract seals and other salmon predators to these areas, possibly increasing predation on wild salmon. Additionally, aquaculture facilities may cause degradation of surrounding water quality. Nutrient enrichment through fish food and waste can degrade water quality and cause toxic algal blooms. Benthic pollutants such as heavy metals and biological deposits of waste and food may also alter the ecology of other organisms and trophic levels.

5.12 Effects of Chemically Treated Construction Materials

Poston (2001) addresses three types of treated wood used in the construction of docks, piers, and floating structures; creosote treated lumber, and two types of metal-based treated wood; ammoniacal copper zinc arsenate treated wood (ACZA), and chromated copper arsenate treated wood (CCA type-C). Because salmon are a migratory species, the most probable means of them contacting treated wood contaminants, at levels high enough to have an adverse affect upon them, is through the consumption of contaminated prey (Poston 2001). Larger streams with higher flow rates are not as likely to accumulate the amounts of contaminants, introduced by treated wood materials, to detrimental levels in aquatic food webs (Poston 2001).

Creosote treatments

Creosote is primarily composed of polycyclic aromatic hydrocarbons (PAH), making up approximately 65-85% of the treating agent, with phenolic compounds making up approximately 10% of the agent, followed by nitrogen, sulfur, and/or oxygenated heterocyclics (EPRI 1995; Brooks 1994). PAH exposure, for prolonged periods, may lead to non-polar narcosis, carcinogenesis, phototoxicity, and hormone regulation disruption (Van Brummelen *et al.* 1998). As an example of how creosote might affect aquatic organisms, Vines *et al.* (2000) studied how creosote would affect egg-larval development of the Pacific herring (*Clupea pallasii*). The tests exposed the fish eggs to

aged creosote treated wood, kiln dried untreated Douglas fir, and a no wood control treatment. Successful hatching was greatest in the control treatment at 89%, followed by 73% in the untreated wood treatment, 9% of free floating eggs in the creosote treatment hatched, with 0% of the eggs attached to the creosote wood hatching, 100% of the 9% of hatched eggs within the creosote treatment were abnormal (i.e., scoliosis, abnormal fluid retention, and fluid accumulation around the heart) specimens. According to Poston (2001), creosote treated timbers should not be used for structures when building near salmon spawning habitat due to the longevity of creosote's leaching characteristics.

Metal based treatments

ACZA and CCA type-C are two types of metal based wood treatment usually applied to Douglas fir and Western Hemlock in the Pacific Northwest. ACZA entails the fixation of an aqueous solution of 25% zinc oxide, 50% cupric oxide (copper base), and 25% arsenic pentoxide. CCA type-C is also a multifarious compound made-up of 47.7% chromium trioxide (chromate base), 18.5% cupric oxide, and 34% arsenic pentoxide (AWPA 1996). The long term effects of CCA type-C and ACZA treated woods are discernible in the accretion of contaminants in sea-floor sediment and the direct impacts of the biotic communities that colonize the treated wood structure (Poston 2001). The leaching rates of the trace metals in both types of treatments are at their greatest when first immersed into the aquatic environment (Poston 2001). However, the amount of metals leaching into the water column does dissipate over time (days to weeks) (Poston 2001). If metal based treated wood is to be used, the wood should first be sufficiently weathered to lower the level of leaching when introduced into the water column (Poston 2001).

5.13 Effects of Dredging

Dredging is the practice of removing sediment from an aquatic system and commonly occurs in freshwater, estuarine, and marine environments. Nightingale and Simenstad (2001b) place dredging practices into one of two categories, the creation of new projects and waterway deepening; or maintenance dredging for the purpose of up-keeping already existing channels. New construction dredging is outlined by Nightingale and Simenstad (2001b) as "any modification that expands the character, scope, or size of an existing, authorized project." Whereas maintenance dredging is the periodic upkeep of already existing sites and/or channels. Nightingale and Simenstad (2001b) list some examples of why dredging might be used including to maintain water depths, create or expand marinas, mine gravel or sand for shoreline armoring, open channels for passage of flood flows, retrieve cement mixture ingredients, and remove contaminated sediments. The method of dredging to be used in an area is directly dependent upon the nature of the habitats sediment, its contamination level, material characteristics, amount of material to be dredged, and the type of disposal planned (Nightingale and Simenstad 2001a). Two common dredging methods used are hydraulic dredging and mechanical dredging (Nightingale and Simenstad 2001a).

Before dredging begins, sediment is chemically tested to decide upon the safest method of disposal. If the material is chemically sound, the sediments are sometimes disposed of through open-water disposal or alternatively, through the practice of "beneficial uses" (Nightingale and Simenstad 2001a). Open-water disposal can take place via a direct

pipeline discharge, mechanical placement, or by ship (such as the hydraulic dredging ships). Whereas the practice of beneficial uses employs the dredged sediments for human and/or environmental purposes such as landfill, and construction needs (e.g., ingredients for cement mixtures) or habitat restoration (e.g., to replenish degraded natural sedimentation processes) (Nightingale and Simenstad 2001a). If sediment collected during dredging is shown to be potentially toxic to biota, the sediments will typically be disposed of via confined disposal facilities (Nightingale and Simenstad 2001a). Confined disposal facilities are disposal units that have been mechanically and structurally engineered to hold contaminated material dredged-up from the sea-floor and are used to isolate the sediment from all adjacent water sources.

Hydraulic Dredging

Hydraulic dredging includes the use of hopper dredges and cutterhead pipeline dredges. Hopper dredges are ships equipped with a suction pipe that is connected to a draghead, and have a hold aboard the ship for the temporary storage and moving of the dredged sediment (Nightingale and Simenstad 2001a). The draghead is moved along the bottom as the ship slowly moves forward, the material that is dredged-up is suctioned up the hose and into the holding tank aboard the vessel for later transport (Nightingale and Simenstad 2001a). Similar to the draghead dredging method is the cutterhead pipeline dredge, which utilizes a rotating cutter on the head of the suction hose. The material that is loosened by the cutter is drawn up the suction hose and into the holding tank of the ship (Nightingale and Simenstad 2001a).

Mechanical Dredging

Mechanical dredging includes bucket dredging and agitated dredging. Bucket Dredges are dredges that employ the use of large steel buckets that are lowered to the sea-floor via a crane. After the jaws have contacted the bottom they sink into the sediment, at which point the bucket is lifted from the bottom causing the jaws to close, lifting the sediment out of the water into the air, which it is then placed into a barge, ship, or truck for transportation to a dumping area (to be discussed below) (Nightingale and Simenstad 2001a). An adaptation of the bucket dredge is the closed environmental bucket dredge (Nightingale and Simenstad 2001a). They are modified dredges (closed bucket design) for the purpose of reducing the amount of sediment spill and/or flow during dredging (Nightingale and Simenstad 2001a). Another form of mechanical dredging is the practice of agitation dredging. It is accomplished by moving fine-grained sediments into the current of an ebbing tide, allowing natural water flows to carry away the dredged material (Nightingale and Simenstad 2001a).

5.13.1 Water quality

Dredging can cause a range of negative impacts to water quality in the effected area. Of greatest concern is the associated increase in the water's turbidity (the measure of suspended solids in the water column). Increased turbidity can have adverse affects upon the impacted area's fish community that include a range of impacts from difficulty absorbing oxygen from the water, altered feeding behavior, and changes in predator-prey relationships (Nightingale and Simenstad 2001a). In addition, increased turbidity causes reductions in the light's ability to penetrate the water column. Light penetration plays a

central role in the level of productivity of aquatic environments, predator/prey relationships, schooling behavior, and fish migration (Nightingale and Simenstad 2001a).

Juvenile salmonids migrating through and residing in estuaries are naturally capable of coping with high levels of turbidity, however, suspended solids (SS) introduced via dredging can produce material that is of the right size and shape to adversely affect the young salmon by inhibiting their ability to diffuse oxygen through their gills (Nightingale and Simenstad 2001a). According to Nightingale and Simenstad (2001b), SS in concentrations of ≥ 4000 mg/L, have been shown to cause erosion to the terminal ends of fish gills. In addition to impacting juvenile salmon, suspended sediments at levels of 20 mg/L and 10 mg/L have been shown to result in avoidance behaviors from Rainbow smelt, and Atlantic herring, respectively (Wildish and Power 1985).

5.13.2 Fish communities

Another detrimental effect of dredging is fish entrainment. Entrainment is the direct uptake of a fish into the suction hose of a ship that is using hydraulic dredging methods. Entrainment rates are measured by the number of organisms per cubic yard of sediment that is dredged (Nightingale and Simenstad 2001a) and have been shown to have the greatest impact on demersal fish species (Larson and Moehl 1990; McGraw and Armstrong 1990). McCabe (1997) found that juvenile white sturgeon have been entrained while dredging; this is attributed to the fish's small size, limited swimming abilities, and its nature to remain close to the bottom. Also, in Canada, juvenile salmonids have been observed as the most frequently entrained fish while dredging activities are occurring, due to constricted waterways that make it difficult for the fish to avoid the area being dredged (McGraw and Armstrong 1990, Larson and Moehl 1990).

5.14 Effects of Shoreline Armoring

Various shoreline armoring techniques, including bulkheads, revetments, and sea walls are used to maintain and create functional land for society. Bulkheads, revetments, and sea walls are similar to breakwaters, in that they dissipate wave energy, but also, as the collective name "shoreline armoring" implies, serve the purpose of shoreline stabilization. Activities associated with shoreline armoring have been shown to have negative impacts upon nearshore marine and estuarine ecosystems.

Bulkheads

Bulkheads are vertical shoreline structures constructed of concrete, rock, or wood, and serve the purpose of providing a vertical separation between land and water (USACE 1984). They are built to protect land areas from erosion by hydraulic water processes, create waterfront real estate, and for vessel moorage (USACE 1984; Mulvihill *et al.* 1980).

Revetments

Revetments protect shorelines against the erosive forces of water bodies, but unlike bulkheads, are built on a sloping gradient, as opposed to being a vertical standing

structure; and are usually built of similar materials as bulkheads (USACE 1984, Mulvihill *et al.* 1980).

Sea Walls

Sea walls are large free-standing structures typically constructed with a combination of stone, pilings, and/or concrete (Williams and Thom 2001). Sea walls are constructed to protect bluffs and banks from the onslaught of moderate to severe wave movements (USACE 1984; Williams and Thom 2001). Often they are built with a splash apron at the crest of the wall so that the wave energy is redirected away from the wall and embankment (Williams and Thom 2001).

5.14.1 Habitat

The placement of hardened structures along natural shorelines can influence erosion processes that alter the structure and the function of native habitats at areas both near and distant from the site of impact (Williams and Thom 2001). Shoreline modification in the Northwest has been connected to the loss of habitat for use by forage fish such as the surf smelt, changes in substrate composition, and reduced egg survival rate for resident fishes (Penttilla and Aguero 1978; Penttilla 2000).

Bulkheads

Bulkheads have been shown to increase turbulence and wave scour, both of which lead to the desecration of marsh vegetation and prevent intertidal vegetation re-establishment (Engineering Science 1981; Watts 1987). Reductions in egg survival are thought to be associated with the loss of riparian cover (Penttilla and Aguero 1978; Penttilla 2000).

Revetments

Li *et al.* (1984) found that both larval and juvenile fish densities were lower along revetments when compared to natural shorelines. In this same study it was found that adult fish densities along revetments were comparable to natural shorelines (Li *et al.* 1984). The high variability of natural cover (structural diversity), water flow rates and depths are attributed to the higher densities of larval and juvenile fish along the natural shoreline in comparison to a revetment (Li *et al.* 1984).

Sea Walls

The construction of sea walls has been associated with substrate coarsening as well as changes in dominant benthic species, and altered hydrodynamic processes along the affected shoreline (Ahn and Choi 1998).

5.14.2 Behavior

According to Williams and Thom (2001), juvenile salmonids in the Pacific Northwest may be adversely affected by various methods of shoreline armoring that change the functional design of estuarine and marine habitats. Migration routes may be altered due to an introduction of large impassable obstructions, a lack of nursery areas due to habitat shift, and loss of habitat structure (e.g., eel grass) could potentially have a detrimental affect upon juvenile salmon (Williams and Thom 2001). The alteration of wave energy associated with shoreline armoring may lead to a change in the flow of nutrients (loss of

forage) in an area, may lead to higher predation upon migrating salmon fry and smolts due to lack of vegetation cover, and may potentially reduce areas for young salmon to make their necessary physiological transitions to marine habitat (Williams and Thom 2001).

5.15 Effects of Pilings, Piers, and Overwater Structures

Pilings, driven into the sea-floor or river bed by a large pneumatic hammer, are used to support piers, and may lead to habitat desecration through sedimentation relocation, noise, substrate transformation, and altered water flow characteristics (Nightingale and Simenstad 2001b). Piers are raised structures, walkways, and/or over-water building foundations, supported by pilings. Both piers and pilings can be constructed out of materials such as wood, steel and/or concrete. According to Nightingale and Simenstad (2001a), large piers overhanging the water can potentially affect habitat vegetation, animal actions, fish migration, predation levels, substrate, and current flow.

In addition, Nightingale and Simenstad (2001a) assert that overwater structures (e.g., docks, covered moorages, houseboats, marinas, etc.) can have damaging effects upon the biotic and abiotic constituents of an ecosystem due to shoreline modifications (as discussed above), loss of light transmission and increased predation, both of which may lead to a shift in trophic structure and overall changes in ecosystem function. Stationary floating structures such as docks, floating breakwaters, mooring buoys, and houseboats have a larger shade footprint than that of a raised structure, such as a pier (Burdick and Short 1995).

5.15.1 Habitat

Pilings, piers, and overwater structures may lower the amount of light reaching the sea-floor. In addition, the potential groundings of floating structures during low tides may scour the sea floor and kill resident organisms (Nightingale and Simenstad 2001b).

Pilings

Placement of pilings into a marine habitat can transform habitat by mobilizing bottom sediments and contaminants (Nightingale and Simenstad 2001b). Over time shellfish (e.g., mussels) that attach to docks and pilings begin to accumulate on the structures, and when preyed upon by other organisms (e.g., seastars) shellhash begins to overlay the adjacent substrate layer (Nightingale and Simenstad 2001b). This new substrate provides a first-rate habitat for species (e.g., crabs) that further desecrate eel grass vegetation due their incessant burrowing (Thom and Shreffler 1996).

Piers

The shade produced by a pier may lead to a localized inhibition of aquatic vegetation growth (e.g., eel grass). As a result, a loss of vegetation may lead to a cascade of ecological impacts ranging from the loss of autotrophs up to disrupted ecosystem processes including the loss of the organisms that depend on the vegetation for either food and/or protective cover along their migration corridor (Nightingale and Simenstad 2001b).

Floating docks

Floating docks can have a severe impact upon aquatic macrophytes, for example three out of four stationary docks studied by Burdick and Short (1999) were shown to have no rooted eel grass underneath them. The effects of shade introduced upon eel grass by a stationary dock can be observed in as little as 18 days (Backman and Barilotti 1976). Likewise, a study in Montauk N.Y. reported the exclusion of eel grass underneath a floating pier (Ludwig *et al.* 1997). However, Penttila and Doty (1990) found no eel grass loss underneath a movable floating dock that was held in place by anchors and chains. It is believed that the floats ability to pivot and move with the tide and waves allowed sufficient light to penetrate to the seafloor; allowing the eel grass to persist. As mentioned above, the primary threat accompanying the disappearance of nursery habitat (e.g., eel grass) is a loss in the number of available prey species (forage fish) (Nightingale and Simenstad 2001b).

Floating breakwater

Floating breakwaters and wave boards can potentially have the same affect upon habitat and vegetation if placed in shallow water. Under these conditions, loss of aquatic vegetation, alterations of fish migration routes, and changes in substrate can occur as a result of floating breakwaters. However, the effect of floating breakwaters is significantly less profound than the effects of permanent breakwaters (Nightingale and Simenstad 2001b).

Mooring buoys

Mooring buoys anchored to the bottom have been observed scouring the sea-floor by their fastening chain scraping along bottom (Williams and Betcher 1996). Barges, rafts, and booms may also potentially pose this same risk when at anchor (Nightingale and Simenstad 2001b).

5.15.2 Behavior

The shade produced by a pier may influence fish behavior, and at times, can result in artificially increased mortality rates. For example, Duffy-Anderson and Able (1999) performed a study to observe the impact of shade generated by a pier on juvenile fish in New York. The experiment consisted of caged fish under a pier in the shade and caged fish along the edge of the pier in the light. They found that the fish under the pier showed periods of starvation, which could potentially lead to them becoming an easier target as a prey animal. The fish placed at the edge of the light and shaded areas of the pier showed high rates of growth, which led them to believe that shade greatly affected the harmonization of habitats encroached upon by piers.

The loss of light due to overwater structures has been well documented and is known to alter Pacific salmon smolt migration paths (Ali 1959, 1962; Browman *et al.* 1993; Coughlin and Hawryshyn 1993; Dera and Gordon 1968; Fields and Finger 1954; Hawryshyn and Harosi 1993; Nemeth 1989; Novales-Flamique and Hawryshyn 1996; Puckett and Anderson 1987). Studies in the Pacific Northwest have shown that juvenile Pacific salmon prefer to travel along the edge of light and shade and avoid entering shaded habitats (Pentec Environmental 1997; Weitkamp 1982; Heiser and Finn 1970).

This behavior may force young salmonids to venture into the deeper reaches of their environment (e.g., in order to swim around the pier) possibly exposing them to a higher number of piscivorous predators.

In addition to avoiding shaded areas, studies in Puget Sound have shown that Pacific salmonids rely heavily upon their sight to capture prey, as well as avoid becoming prey themselves (Nightingale and Simenstad 2001b). Both field and laboratory studies show that sight dependent fish species lose their ability to see and fish prey capture has been observed being brought to a halt when an intense light contrast (such as shade introduced by a dock or other floating structure) is present (Nightingale and Simenstad 2001b). Dispersion and changes in direction in order to avoid a light contrast has also been observed in fish schools (Nightingale and Simenstad 2001b). Although floats may hinder the vision of juvenile salmon making them less able to catch prey and also making them more susceptible to larger predators, there is no empirical evidence to support allegations of higher mortality rates upon juvenile salmonids directly attributed to the introduction of a float (Penttila and Aguero 1978; found in Nightingale and Simenstad 2001b).

5.15.3 Water flow

Pilings can alter the flow of water both around the pilings as well as over the substrate, changing the bathymetry and flow of water in the immediate area (Ratte 1985; Penttila and Doty 1990). Another harmful effect upon juvenile salmonids associated with pile driving is the possibility of damaged hearing from the noise; as well as undue stress (Nightingale and Simenstad 2001b).

5.16 Effects of Breakwaters

Breakwaters, often created to protect marinas, may impact nearshore hydrological processes, such as current patterns and sediment transport, as well as temperature, salinity, and water levels (Nightingale and Simenstad 2001b; Williams and Thom 2001). Breakwaters are self-supporting structures that are built with the purpose of dissipating wave energy created by weather, tidal movements, and boat traffic (Mulvihill *et al.* 1980, USACE 1984) and therefore inherently alter natural ecosystem processes. Breakwaters can be built as either a floating or standing stationary structure, and can be made of wood, rock, concrete, and/or metal (Williams and Thom 2001).

5.16.1 Behavior

Williams and Thom (2001) suggest that breakwaters can have an impact upon the behavior of different fish species due to physical obstructions, current alterations, and physiochemical influences. Schools of Pacific salmon fry and forage fish were observed congregating behind breakwaters, which lead to concerns of the effects of water pollution (e.g., from marinas) on the resident fish communities (Heiser and Finn 1970; Penttila and Aguero 1978). It is also believed that breakwaters may impede travel corridors for many fish species, exposing salmon fry to an increased frequency of predation by other organisms, as well as prolonged exposure to water contaminants introduced by boat marinas (Williams and Thom 2001).

5.17 Effects of Tide Gates

Tide gates are a flow control apparatus that only allow a uni-directional flow of water to take place. They can typically be found in culverts placed through dikes allowing normal stream flow one way, but not allowing saline water brought up by high tides into the stream channel (Bates 1997; Williams and Thom 2001). When closed, the gate acts as a barrier to fish movement and when open may at times prove impassable for many fish species due to high flow rates (Bates 1997). Tide gates also have harmful impacts upon the hydrology, water quality, sedimentation process, and the physical connectiveness between habitats (Williams and Thom 2001).

5.18 Effects of Beach Nourishment

Beach nourishment is looked upon as a sacrificial layer of gravel (or similar substrate) used to prevent shoreline erosion due to floods, tidal movement, storms, and wave action (USACE 1984). According to Williams and Thom (2001) most beach nourishment projects in the Puget Sound area have used a gravel size substrate to extend the shoreline. It has been specified in some projects that the gravel should be between 1.5 to 6.3 mm in diameter (Williams and Thom 2001). The gravel is transported in by dump truck and then spread by bulldozer to match, as best as possible, the contour of the natural shoreline (Williams and Thom 2001).

Improper design and execution of beach nourishment efforts will result in negative impacts including but not limited to changes in wave action, habitat burial, increased turbidity, and loss of foraging, nesting, and breeding habitat (National Research Council 1995). Cost may also be a factor in determining the acceptability of introducing a beach nourishment program to an area (Williams and Thom 2001).

5.18.1 Habitat

Beach nourishment attempts to minimize the negative impacts of shoreline stabilization. The soft approach of beach nourishment is considerably less harmful than that of bulkheads, revetments, and sea walls (Downing 1983). The effect of beach nourishment upon a habitat may potentially be adverse if suitable substrate is not used at the administered site (Williams and Thom 2001)

One means of beach nourishment is the replanting and mending of damaged riparian zones. Re-establishment of plants, shrubs, and trees can provide a natural support structure that retards substrate movement through bank stabilization (Myers 1993).

Beach nourishment (*i.e.* beach graveling) has been associated with rises in clam density (Thompson and Cooke 1991) as well as in quantities of epibenthic prey resources for juvenile salmonids (Simenstad *et al.* 1991).

5.19 Effects of Marinas

Marinas are an assemblage of either floating docks, or fixed piers, usually found behind rubble mound breakwaters, and are used for boat moorage (Nightingale and Simenstad 2001b). The purpose of a marina is to provide a mooring area that is protected from

wave energy and because of the potential amount of area that may be covered by a marina, the possibility of a negative impact to the areas biotic and abiotic communities can be significant (Nightingale and Simenstad 2001b). Construction and maintenance of marinas has been associated with increased levels of light reduction, localized habitat impacts, alterations in dispersal of wave energy, and loss of sediment transport (Nightingale and Simenstad 2001b). Breakwaters, often created to protect marinas, interfere by altering current flow, sediment transport, and substrate transformation (Nightingale and Simenstad 2001b; Williams and Thom 2001).

5.19.1 Habitat

The construction of a marina may convert an intertidal zone into a subtidal zone and therefore could potentially have negative repercussions upon the affected areas aquatic vegetation (Nightingale and Simenstad 2001b). Carlisle (1977) described marinas as potential water traps, creating ideal conditions for a dinoflagellate bloom; and such bloom die-offs may potentially lead to lower levels of dissolved oxygen, and in-turn develop into a massive fish kill due to the lack of oxygen in the water column.

5.19.2 Water Quality

The impact marinas have on water quality is dependent upon the amount of use the marina receives. With greater use comes the higher probability of contaminants (e.g., paints, oil and fuel spills, boat exhaust) being spilled into the water, and becoming introduced into the tissues of fish that both congregate, and migrate through the marina's habitat (Nightingale and Simenstad 2001b). *The potential effects upon the fish community can be found within the breakwater, piers and pilings, and floating structures sections.*

Literature Cited

- Ackefors, H., and Enell, M. 1994. The release of nutrients and organic matter from aquaculture systems in Nordic countries. *J. Appl. Ichthyol.* 10: 225 – 241
- Ahn, I.-Y. and J.-W. Choi. 1998. Macrobenthic communities impacted by anthropogenic activities in an intertidal sand flat on the West Coast (Yellow Sea) of Korea. *Marine Pollution Bulletin* 36(10): 808-817
- Alexander, G.R. 1977. Consumption of small trout by large predatory brown trout in the North Branch of the Au Sable River, Michigan. Fisheries Research Report No. 1855. Michigan Department of Natural Resources Fisheries Division. Pages 1-26
- Ali, M. A. 1962. Influence of light intensity on retinal adaptation in Atlantic salmon (*Salmo salar*) yearlings. *Can. J. Zool.* 40: 561-570
- Ali, M.A. 1959. "The ocular structure, retinomotor and photobehavioral responses of juvenile Pacific salmon." Doctoral Dissertation, Univ. British Columbia
- Allen, R. 1940. Studies on the biology of the early stages of the salmon (*Salmo salar*): growth in the river Eden. *Journal of Animal Ecology* 9(1): 1-23
- American Rivers, Friends of the Earth, and Trout Unlimited. 1999. Dam Removal Success Stories: Restoring Rivers Through Selective Removal of Dams That Don't Make Sense. American Rivers, Washington D.C.
- Andreassen, P.M.R., M.B. Martinussen, N.A. Hvidsten, and S.O. Stefansson. 2001. Feeding and prey-selection of wild Atlantic salmon post-smolts. *J. Fish. Biol.* 58: 1667-1979
- Annear, T., I. Chisholm, H. Beecher, A. Locke, and 12 other others. 2004. Instream Flows for riverine resource stewardship, revised edition. Instream Flow Council, Cheyenne, WY
- Anthony, V.C. 1994. The significance of predation on Atlantic salmon. In: Calabi, S. and A. Stout [eds.] A Hard Look at Some Tough Issues. NE Atlantic Salmon Mgmt. Conf. Silver Quill, Camden Maine, p. 240 – 288
- Armstrong, D.L. K.P Griffin, and M. Danner. 1999. Phosphorous and the Environment. *Better Crops*. Vol. 83(1): 37-39
- Armstrong, J. D., Kemp, P., Kennedy, G., Ladle, M., Milner, N., 2002. Habitat requirements of Atlantic salmon and brown trout in rivers and streams. *Fisheries Research* 1428: 1-28

- Atkins, C.G. and N.W. Foster. 1869. *In* Reports of the Commissioners of Fisheries of the State of Maine for the Years 1867 and 1868. Owen and Nash, Printers to the State, Augusta, ME
- Bachman, R. 1984. Foraging behavior of free ranging wild and hatchery brown trout in a stream. *Trans. Am. Fish. Soc.* 113: 1-32
- Backman, T. W. and D.C. Barilotti. 1976. Irradiance reduction: effects on standing crops of the eelgrass *Zostera marina* in a coastal lagoon. *Marine Biology* 34: 33-40
- Baker, C. 2004. Surveyed Road Crossings and Dams in the Piscataquis River Drainage. U.S. Fish and Wildlife Service. East Orland, ME. 3 pp. and CD
- Baker, J.P. and Schofield, C.L. 1980. Aluminum toxicity to fish as related to acid precipitation and Adirondack surface water quality. *Proc. Int. Conf. Ecol. Impact Acid Precip.* (D. Drablos and A. Tollan, eds.) Norway, 1980, SNSF-Proj. 292 pp.
- Bakke, Tor A., and Philip D. Harris. 1998. Disease and parasites in wild Atlantic salmon (*Salmo salar*) populations. *Can. J. Fish. Aquat. Sci.* 55 (S1): 247-266
- Bates, K. M. 1997. Fishway design guidelines for Pacific salmon. Washington Department of Fish and Wildlife, Working Paper 1.6, 1/97, Olympia, Washington
- Baum, E.T. 1997. Maine Atlantic Salmon: A National Treasure, 1st Ed. Hermon, ME: Atlantic Salmon Unlimited
- Baum, E.T. and A.L. Meister. 1971. Fecundity of Atlantic salmon (*Salmo salar*) from two Maine Rivers. *Journal of the Fisheries Research Board of Canada* 28(5): 764-767
- Beamish, R.J. 1976. Acidification of lakes in Canada by acid precipitation and resulting effects on fishes. *Water, Air and Soil Pollution* 6:501-514
- Beiningen, K. T. 1976. Fish runs. Pages E-1-E-65 *In*: Investigative reports of Columbia River fisheries project. Pacific Northwest Regional Commission, Vancouver, Washington
- Beland, K. F. 1981. Atlantic salmon spawning survey and evaluation of natural spawning success. State of Maine. Project report No. AFS-20-R
- Beland, K.F., J.F. Kocik, J. Van de Sande, and T.F. Sheehan. 2001. Striped Bass predation upon Atlantic salmon smolts in Maine. *Northeastern Naturalist*. 8(3): 267-274
- Beland, K.F., Jordan, R.M., Meister, A.L. 1982. Water depth and velocity preferences of spawning Atlantic salmon in Maine rivers. *N. Am. J. Fish. Man.* 2: 11-13

- Beland, K.F., Trial, J.G., and Kocik, J.F. 2004. Use of Riffle and Run Habitats with Aquatic Vegetation by Juvenile Atlantic Salmon. *North American Journal of Fisheries Management*. 24: 525-533
- Bell, M. C. 1986. Fisheries handbook of engineering requirements and biological criteria. U.S. Army Corps of Engineers, Office of the Chief of Engineers, Fish Passage Development and Evaluation Program, Portland, Oregon
- Benson J. and R. Sherwood. 2004. Maine's changing population. A summary of structural changes, mobility and regional variations. White paper prepared by The Maine State Planning Office for REALIZE! Maine, Augusta, ME.
- Berg, L., and T.G. Northcote. 1985. Changes in territorial, gill-flaring, and feeding behavior in juvenile coho salmon (*Oncorhynchus kisutch*) following short-term pulses of suspended sediment. *Can. J. Aquat. Sci.* 42(8): 1410-1417
- Berkamp, G., M. McCartney, P. Dugan, J. McNeely, and M. Acreman. 2000. Dams, ecosystem functions and environmental restoration. Thematic Review II.1 prepared as an input to the World Commission on Dams, Cape Town, www.dams.org
- Beschta, R. L., J. R. Boyle, C. C. Chambers, W. P. Gibson, S. V. Gregory, J. Grizzel, J. C. Hagar, J. L. Li, W. C. McComb, M. L. Reiter, G. H. Taylor, and J. E. Warila. 1995. Cumulative effects of forest practices in Oregon. Oregon State University, Corvallis. Prepared for the Oregon Department of Forestry. Salem, Oregon
- Beschta, R. L., R. E. Bilby, G. W. Brown, L. B. Holtby, and T. D. Hofstra. 1987. Stream temperature and aquatic habitat: fisheries and forestry interactions. Pages 191-232 *In*: E. O. Saki and T. W. Cundy, editors. *Streamside management: forestry and fishery interactions*. University of Washington, College of Forest Research, Seattle, WA
- Bilby, R.E., B.R. Fransen, and P.A. Bisson. 1996. Incorporation of nitrogen and carbon from spawning coho salmon into the trophic system of small streams: evidence from stable isotopes. *Can. J. Fish. Aquat. Sci.* 53: 164-173
- Bisson, P. A., and R. E. Bilby. 1982. Avoidance of suspended sediment by juvenile Coho salmon. *North American Journal of Fisheries Management*. 4: 371-374
- Bjornn, T. C. 1968. Survival and emergence of trout and salmon fry in various gravel-sand mixtures. Pages 80-88 *In*: *Logging and salmon: proceedings of a forum*. American Institute of Fishery Research Biologists, Alaska District, Juneau, AK
- Bjornn, T. C., D. W. Reiser. 1991. Habitat requirements of salmonids in streams. *In*: *Influences of Forest and Rangeland Management on Salmonid Fishes and Their Habitats*. American Fisheries Society Special Publication 19:83-138

- Black, K.D., Kiemer, M.C.B, and Ezzi, I.A. 1996. The relationships between hydrodynamics, the concentration of hydrogen sulphide produced by polluted sediments, and fish health at several marine cage farms in Scotland and Ireland. *J. Appl. Ichthyol.* 12: 15- 20
- Blackwell, B.F. and F. Juanes. 1998. Predation on Atlantic salmon smolts by striped bass after dam passage. *North American Journal of Fisheries Management* 18: 936-939
- Bley, P. W. and J. R. Moring. 1988. Freshwater and ocean survival of Atlantic salmon and steelhead: A synopsis. Biological report 88(9). Maine Cooperative Fish and Wildlife Research Unit. University of Maine, Orono, ME
- Bley, P.W. 1987. Age, growth, and mortality of juvenile Atlantic salmon in streams: a review. *Biological Report* 87(4). U.S. Fish and Wildlife Service, Washington, D.C.
- Bovee, K.D., B.L. Lamb, J.M. Bartholow, C.D. Stalnaker, J. Taylor, and J. Henriksen. 1998. Stream habitat analysis using the Instream Flow Incremental Methodology. Information and Technical Report USGS/BRD-1998-0004. 131pp. U.S. Geological Survey, Biological Resources Division, Fort Collins, CO
- Brodeur, J.C., F. Okland, B. Finstad, D.G. Dixon, and R.S. McKinley. 2001. Effects of Subchronic Exposure to Aluminum in Acidic Water on Bioenergetics of Atlantic Salmon (*Salmo salar*). *Ecotoxicology and Environmental Safety* 49: 226-234
- Brodeur, J.C., Ytrestøyl, T., Finstad, B. & McKinley, R. S. 1999. Increase of heart rate without elevation of cardiac output in adult Atlantic salmon (*Salmo salar*) exposed to acidic water and aluminum. *Canadian Journal of Fisheries and Aquatic Sciences.* 56: 184-190
- Brooks, K. M. 1994. Literature Review, Computer Model and Assessment of the Environmental Risks Associated with Creosote Treated Wood Products Used in Aquatic Environments. August 30, 1994. *Aquatic Environmental Sciences*, Port Townsend, WA. 136pp. (Reissued in 1997)
- Browman, H. I., I. Novales-Flamarique, and C.W. Hawryshyn. 1993. Ultraviolet photoreception contributes to prey search behavior in two species of zooplanktivorous fishes. *J. Exp. Biol.* 186: 187-198
- Brown, S.B., R.E. Evans, H.S. Majewski, G.B. Sangalang, and J.F. Klaverkamp. 1990. Responses of plasma electrolytes, thyroid hormones, and gill histology in Atlantic salmon (*Salmo salar*) to acid and limed river waters. *Canadian Journal of Fisheries and Aquatic Sciences.* 47(12): 2431-2440
- Budy, P., G.P. Thiede, N. Bouwes, C.E. Petrosky, and H. Schaller. 2002. Evidence linking delayed mortality of Snake River salmon to their earlier hydrosystem experience. *North American Journal of Fisheries Management* 22: 35-51

- Burdick, D.M. and F.T. Short. 1999. The effects of boat docks on eelgrass beds in coastal waters of Massachusetts. *Environmental Management* 23(2): 231-240
- Burner, C. J. 1951. Characteristics of spawning nests of Columbia River salmon. U.S. Fish and Wildlife Service. *Fish. Bull.* 52(61): 97-110
- Calkins, D.J. 1988. Literature Review and Assessment: Winter Habitat Studies Conducted for Atlantic Salmon, Brook, Brown, and Rainbow Trout. Forest Service – Department of Agriculture Green Mountain and White Mountain National Forests Rutland, VT and Laconia, NH respectively. Agreements R9-WM-FIS-010 and 11TU88001
- Carlin, B. 1967. Salmon tagging experiments. Fisheries Research Board of Canada. Translated from Swedish. Swedish Salmon Research Institute (1965), Report LFI Medd. 1/1965
- Carlisle, J. 1977. Pers. Comm. In: Biological Impacts of Minor Shoreline Structures on the Coastal Environment: State of the Art Review. FWS/OBS-77/51 ed., E. L. Mulvihill, C.A. Francisco, J.B. Glad, K.B. Kaster, and R.E. Wilson Vol. 2. U.S. Fish and Wildlife Service
- Carter, T.J., G.J. Pierce, J.R.G. Hislop, J.A. Houseman and P.R. Boyle. 2001. Predation by seals on salmonids in two Scottish estuaries. *Fish. Mgmt. and Ecol.* 8(3): 207-225
- Casillas, E., J. E. Stein, M. R. Arkoosh, D. W. Brown, D. A. Misitano, S. L. Chan, and U. Varanasi. 1993. Effects of estuarine habitat quality on juvenile salmon: I. Chemical contaminant exposure, and II. Altered growth and immune function. *In: Coastal Zone 93 Proceedings, The Eighth Symposium on Coastal and Ocean Management, July 19-23, 1993. New Orleans, Louisiana.*
- Cederholm, C. J., R. E. Bilby, P. A. Bisson, T. W. Bumstead, B. R. Fransen, W. J. Scarlett, J. W. Ward. 1997. Response of juvenile coho salmon and steelhead to placement of large woody debris in a coastal Washington stream. *N. Am. J. Fish. Management.* 17: 947-963
- Chadwick, E. M. P. 1982. Stock-recruitment relationship for Atlantic salmon (*Salmo salar*) in Newfoundland rivers. *Can. J. Fish. Aquat. Sci.* 39: 1496-1501
- Chamberlin, T. W., R. Harr, and F. Everest. 1991. Timber harvesting, Silviculture, and watershed processes. Influences of forest and rangeland management on salmonid fishes and their habitats. *American Fisheries Society Special Publication.* 19: 181-205
- Cordone, A.J. and D.W. Kelley. 1961. The influences of inorganic sediment of the aquatic life of streams. *California Fish and Game.* pp. 189-228

- Corliss C., Maine Land Use Regulatory Commission. March 13, 2007. Subject: RE: Peat Mines in Washington County? Electronic mail and phone communications:
- Coughlin, D. J. and C.W. Hawryshyn. 1993. Ultraviolet sensitivity in the torus semicircularis of juvenile rainbow trout (*Oncorhynchus mykiss*). *Vision Res.* 34: 1407-1413
- Cunjak, R. A. 1988. Behavior and microhabitat of young Atlantic salmon (*Salmo salar*) during winter. *Canadian Journal of Fisheries and Aquatic Sciences* 45(12): 2156-2160
- Cunjak, R. A. 1996. Winter habitat of selected stream fishes and potential impacts from land-use activity. *Canadian Journal of Fisheries and Aquatic Sciences.* 53(Suppl.1): 267-282
- Cunjak, R.A., E.M.P. Chadwick, and M. Shears. 1989. Downstream movements and estuarine residence by Atlantic salmon parr (*Salmo salar*). *Canadian Journal of Fisheries and Aquatic Sciences.* 46(9): 1466-71
- Cunjak, R.A., R.L. Saunders, and E.M.P. Chadwick. 1990. Seasonal variations in the smolt characteristics of juvenile Atlantic salmon (*Salmo salar*) from estuarine and riverine environments. *Can. J. Fish. and Aquat. Sci.* 47(4): 813-820
- Cunjak, R.A., T.D. Prowse, and D.L. Parrish. 1998. Atlantic salmon (*Salmo salar*) in winter: "the season of parr discontent"? *Can. J. Fish. Aquat. Sci.* 55 (Suppl. 1): 161-180
- Danie, D., J. Trial, J. Stanley, L. Shanks, and N. Benson. 1984. Species profiles: life histories and environmental requirements of coastal fish and invertebrates (North Atlantic): Atlantic salmon. USFWS, report FWS/OBS-82/11.22
- Daye, P. 1980. Attempts to acclimate embryos and alevins of Atlantic salmon, *Salmo salar*, and rainbow trout, *S. gairdneri*, to low pH. *Canadian Journal of Fisheries and Aquatic Sciences* 37: 1035-1038
- Daye, P. 1981. The impact of acid precipitation on the physiology and toxicology of fish. *International Atlantic Salmon Foundation Special Publication* 10:29-34
- Daye, P. and E. Garside. 1977. Lower lethal levels of pH for embryos and alevins of Atlantic salmon, *Salmo salar* L. *Canadian Journal of Zoology* 55: 1504-1508
- Daye, P. and E. Garside. 1979. Development and survival of embryos and alevins of the Atlantic salmon, *Salmo salar* L., continuously exposed to acidic levels of pH, from fertilization. *Canadian Journal of Zoology* 57: 1713-1718
- Daye, P. and E. Garside. 1980. Structural alterations in embryos and alevins of the Atlantic salmon, *Salmo salar* L., induced by continuous or short-term exposure to acidic levels of pH. *Canadian Journal of Zoology* 58: 27-43

- Decola, J. N. 1970. Water quality requirements for Atlantic salmon, US Department of the Interior. Federal Water Quality Administration, N.E., Region, Boston, Mass. 42 pp.
- Degerman, E., B. Sers, J. Tornblom, and P. Angelstam. 2004. Large woody debris and brown trout in small forest streams – towards targets for assessment and management of riparian landscapes. *Ecological Bulletins* 51: 233-239
- Dempson, J.B., M.F. O'Connell, and M. Shears. 1996. Relative production of Atlantic salmon from fluvial and lacustrine habitats estimated from analyses of scale characteristics. *Journal of Fish Biology* 48: 329-341
- Dera, J. and H.R. Gordon. 1968. Light field fluctuations in the photic zone. *Limnol. Oceanogr.* 13: 697-699
- DeRoche, S.E. 1967. Fishery Management in the Androscoggin River. Fisheries Research Bulletin No. 7. Published under appropriation 7750
- Dieperink, C., B.D. Bak, L.-F. Pedersen, M.I Pedersen and S. Pedersen. 2002. Predation on Atlantic salmon and sea trout during their first days as postsmolts. *J. Fish. Bio.* 61: 848 – 852
- Dill, R., C. Fay, M. Gallagher, D. Kircheis, S. Mierzykowski, M. Whiting, T. Haines. 2001. Water quality issues as potential limiting factors affecting juvenile Atlantic salmon life stages in Maine Rivers. /A report to/: The Maine Atlantic Salmon Technical Advisory Committee (TAC). Ad Hoc Committee on Water Quality. 29pp.
- Dittman, A.H. and T.P. Quinn. 1996. Homing in Pacific salmon: Mechanisms and ecological basis. *Journal of Experimental Biology* 199: 83-91
- Dose, J.J. and B.B. Roper. 1994. Long-term changes in low-flow channel widths within the South Umpqua Watershed, Oregon. *Water Resour. Bull.* 30: 993-1000
- Doudoroff, P., and C.E. Warren. 1965. Environmental requirements of fishes and wildlife: dissolved oxygen requirements of fishes. Oregon Agricultural Experiment Station Special Report 141
- Downing, J. 1983. The coast of Puget Sound: Its processes and development. Washington Sea Grant Program. University of Washington Press, Seattle, Washington. 126pp.
- Driscoll C.T., G.B. Lawrence, A.J. Bulger, T.J. Butler, C.S. Cronan, C. Eager, K.F. Lambert, G.E. Likens, J.L. Stoddard, and K.C. Weathers. 2001. Acidic Deposition in the northeastern United States sources of inputs, ecosystem effects, and management strategies. *BioScience* 51(3): 180-198.
- Driscoll, C.T., Baker, J.P., Bisogni, J. J. & Schofield, C. L. 1980. Effect of aluminum speciation on fish in dilute acidified waters. *Nature* 284: 161-164

- Dudley R. W. and G. A. Hodgkins. 2002. Trends in streamflow, river ice, and snowpack for coastal river basins in Maine during the 20th century. U.S. Geological Survey. Water-Resources Investigations Report 02-4245. 26 pp.
- Dudley R. W. and G. J. Stewart. 2006. Estimated effects of ground-water withdrawals on streamwater levels of the Pleasant River near Crebo Flats, Maine, July 1 to September 30, 2005: U.S. Geological Survey Scientific Investigations Report 2006-5268, 14 pp.
- Duffy-Anderson, J. T., and K.W. Able. 1999. Effects of municipal piers on the growth of juvenile fishes in the Hudson River Estuary: a study across a pier edge. *Marine Biology* 133(3): 409-418
- Duston, J., Saunders, R.L. 1990. The entrainment role of photoperiod on hypoosmoregulatory and growth-related aspects of smolting in Atlantic salmon (*Salmo salar*). *Can. J. Zool.* 68: 707-715
- Dutil, J.D, and J.M. Coutu. 1988. Early marine life of Atlantic salmon, *Salmo salar*, postsmolts in the northern Gulf of St. Lawrence. *Fishery Bulletin* 86: 197 – 212
- EFH Technical Team. 1998. Essential Fish Habitat Source Document. Atlantic salmon (*Salmo salar*) Life History and Habitat Requirements. New England Fisheries Management Council, Saugus, MA
- Egglisshaw, H. J., and P. E. Shackley. 1985. Factors governing the production of juvenile Atlantic salmon in Scottish streams. *Journal of Fish Biology* 27(Supplement A): 27-33
- Einarsson, S.M., D.H. Mills, and V. Johansson. 1990. Utilization of fluvial and lacustrine habitat by anadromous Atlantic salmon, *Salmo salar* L., in an Icelandic watershed. *Fisheries Research*. 10(1-2): 53-71
- Eisler, R., Copper hazards to fish, wildlife, and invertebrates: a synoptic review. 1998. U.S. Geological Survey, Biological Resources Division, Biological Science Report
- Elliott S.R., T. A. Coe, J. M. Helfield, and R. J. Naiman. 1998. Spatial variation in environmental characteristics of Atlantic salmon (*Salmo salar*) rivers. *Can. J. Fish. Aquat. Sci.* 55 (Suppl. 1): 267-280
- Elliott, J. M. 1991. Tolerance and resistance to thermal stress in juvenile Atlantic salmon, *Salmo salar*. *Freshwater Biology*. 25: 61-70
- Elson, P. 1975. Atlantic salmon rivers, smolt production and optimal spawning: an overview of natural production. *In*: J. Bohne and L. Sochasky (eds.), *New England Atlantic salmon Restoration Conference*. Sp. Pub. 6: 96-119. Int. Atl. Salm. Ged. St. Andrews, N.B., Canada

- Elson, P.F. 1941. Eels as a limiting factor in salmon production. MS Report of the Biological Station. Fishery Research Board of Canada. Vol. 213. 9pp
- Elson, P.F. 1969. High temperature and river ascent by Atlantic salmon. International Council for the Exploration of the Sea. 1969/M12 9pp
- Elwood, J.W., J.D. Newbold, R.V. O'Neil, and W. VanWinkle. 1983. Resource spiraling: an operation paradigm for analyzing lotic ecosystems. Pages 3-27 *In*: T.D. Fontaine, III and S.M Bartell, editors. Dynamics of lotic ecosystems. Ann Arbor Science, Ann Arbor, Michigan, USA
- Engineering Science. 1981. Study to determine the impact of landward bulkheads or alternative structures on marshes. Final report prepared for U.S. Dept. of Commerce, NOAA, National Marine Fisheries Service, Northeast Region
- EPRI. 1995. Management Practices for Used Treated Wood, Final Report. EPRI TR-104966. Electric Power Research Institute, Pleasant Hill, California
- Erkinaro, J., E. Niemelä, A. Saari, Y. Shustov, and L. Jørgenson. 1998. Timing of habitat shift by Atlantic salmon parr from fluvial to lacustrine habitat: analysis of age distribution, growth, and scale characteristics. *Can. J. Fish. Aquat. Sci.* 55: 2266-2273
- Erkinaro, J., J.B. Dempson, M. Julkunen, and E. Niemelä. 1997. Importance of ontogenetic habitat shifts to juvenile output and life history of Atlantic salmon in a large subarctic river: an approach based on analysis of scale characteristics. *J. Fish Biol.* 51: 1174-1185
- Erkinaro, J., Y. Shustov, and E. Niemelä. 1995. Enhanced growth and feeding rate in Atlantic salmon parr occupying a lacustrine habitat in the river Utsjoki, northern Scandinavia. *J. Fish Bio.* 47(6): 1096-1098
- Erman, D.C., and D. Mahoney. 1983. Recovery after logging in streams with and without bufferstrips in northern California. Contribution 186. Water Resources Center, University of California Berkeley, Berkeley, CA
- Estes, J.A., and J.F. Palmisano. 1974. Sea Otters: Their Role in Structuring Nearshore Communities. *Science.* 185(4156): 1058-1060
- Everest, F.H., Chapman, D.W., 1972. Interhabitat migration of juvenile Atlantic salmon in a Newfoundland river system. *Can. J. Fish. Biol.* 51, 373-388
- Exley, C., Chappel, J. S. & Birchall, J. D. 1991. A mechanism for acute aluminum toxicity in fish. *Journal of Theoretical Biology.* 151: 417-428
- Fact Sheet FA 27, Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida. First published: September 1992. Reviewed: May 1997, February 2003. <http://edis.ifas.ufl.edu>.

- Fairchild, W., E. Swansburg, J. Arsenault, and S. Brown. 1999. Does an association between pesticide use and subsequent declines in catch of Atlantic salmon (*Salmo salar* L.) represent a case of endocrine disruption? *Environmental Health Perspectives* 107: 349-357
- Fairchild, W.L., S.B. Brown, and A. Moore. 2002. Effects of freshwater contaminants on marine survival in Atlantic salmon. North Pacific Anadromous Fish Commission (NPAFC) Technical Report No. 4
- Farmer, G.J., R.L. Saunders, T.R. Goff, C.E. Johnston and E.B. Henderson. 1989. Some physiological responses of Atlantic salmon (*Salmo salar*) exposed to soft acidic water during smolting. *Aquaculture*, 82: 229-244
- Fay C., M. Bartron, S. Craig, A. Hecht, J. Pruden, R. Saunders, T. Sheehan and J. Trial. 2006. Status review for anadromous Atlantic salmon (*Salmo salar*) in the United States. Report to the National Marine Fisheries Service and U.S. Fish and Wildlife Service. 294 pp
- Fernandez, I.J., L.E. Rustad, S.A. Norton, J.S. Kahl, and B.J. Crosby. 2003. Experimental Acidification Causes Soil Base-Cation Depletion at the Bear Brook Watershed in Maine. *Soil Science Society of America*. 67: 1909-1919
- Fields, P.E. and G.L. Finger. 1954. The reaction of five species of young Pacific salmon and steelhead trout to light. Tech. Rep. 7, UW School of Fisheries, Seattle, WA.
- Findlay, S., and R.L. Sinsabaugh. 1999. Unraveling the sources and bioavailability of dissolved organic matter in lotic aquatic ecosystems. *Marine and Freshwater Research* 50(8): 781-790
- Flanagan, S. M., M. G. Nielsen, K. W. Robinson, and J. F. Coles. 1999. Water quality assessment of the New England coastal basin in Maine, Massachusetts, New Hampshire, and Rhode Island: Environmental settings and implications for water quality and aquatic biota. U.S. Dept. of the Interior - U.S. Geological Survey. Water-Resources Investigations Report 98-4249
- Fleming, I.A. 1996. Reproductive strategies of Atlantic salmon – ecology and evolution. *Rev. Fish Biol. Fish.* 6: 379-416
- Fleming, I.A., B. Jonsson, M.R. Gross, and A. Lamberg. 1996. An experimental study of the reproductive behaviour and success of farmed and wild salmon (*Salmo salar*). *Journal of Applied Ecology* 33: 893-905
- Fleming, I.A., K. Hindar, I.B. Mjølnerod, B. Jonsson, T. Balstad, and A. Lamberg. 2000. Lifetime success and interactions of farm salmon invading a native population. *The Royal Society*. 267: 1517-1523
- Forsberg, C. 1992. Will an increased greenhouse impact in Fennoscandia give rise to more humic and coloured lakes? *Hydrobiologia* 229: 51-58

- Fraser, P.J. 1987. Atlantic salmon, *Salmo salar* L., feed in Scottish coastal waters. *Aquaculture and Fisheries Management*. 18: 243-247
- Frazer, D. W., J. G. McColl, and R. F. Powers. 1990. Soil nitrogen mineralization in a clearcutting clironosequence in a northern California conifer forest. *Soil Science Society of America Journal* 54: 1145-1152
- Freeman, C., C.D. Evans, D.T. Monteith, B. Reynolds, and N. Fenner. 2001. Export of organic carbon from peat soils. *Nature* 412: 785
- Freeman, C., N. Fenner, N.J. Ostle, H. Kang, D.J. Dorrick, B. Reynolds, M.A. Lock, D. Sleep, S. Hughes, and J. Hudson. 2004. Export of dissolved organic carbon from peatlands under elevated carbon dioxide levels. *Nature* 430: 195-198
- Fried S.M., J.D. McCleave, and G.W. LaBar. 1978. Seaward Migration of Hatchery – Reared Atlantic Salmon, *Salmo salar*, smolts in the Penobscot River Estuary, Maine: Riverine Movements. *J. Fish. Res. Board Can.* 35: 76-87
- Friedland, K. D. 1998. Ocean climate influence on critical Atlantic salmon (*Salmo salar*) life history events. *Can. J. Fish. Aqua. Sci.* 55(S1): 119-130
- Friedland, K.D., and Reddin, D.G. 1993. Marine survival of Atlantic salmon from indices of post-smolt growth and sea temperature. *In: Salmon in the sea and new enhancement strategies. Edited by D. Mills. Fishing News Books, Blackwell Scientific Publications Ltd.* pp. 119–138
- Friedland, K.D., D.G. Reddin, and J.F. Kocik. 1993. Marine Survival of N. American and European Atlantic salmon: effects of growth and environment. *ICES J. of Marine Sci.* 50: 481- 492
- Friedland, K.D., D.G. Reddin, and M. Castonguay. 2003a. Ocean thermal conditions in the post-smolt nursery of North American Atlantic salmon. *ICES Journal of Marine Science* 60(2): 343-355
- Friedland, K.D., D.G. Reddin, J.R. McMenemy, and K.F. Drinkwater. 2003b. Multidecadal trends in North American Atlantic salmon (*Salmo salar*) stocks and climate trends relevant to juvenile survival. *Can. J. Fish. Aquat. Sci.* 60: 563-583
- Friedland, K.D., J. Dutil, and T. Sadusky. 1999. Growth Patterns in postsmolts and the nature of the marine juvenile nursery for Atlantic salmon, *Salmo salar*. *Fishery Bulletin*. 97(3): 472-481
- Fry, F.E.J. 1947. Effects of the environment on animal activity. *Univ. Toronto Studies Biol. Ser. No. 55. Publ. Ontario Fish. Res. Lab.* 68. 62pp.
- Furniss, M.J., T. D. Roelofs, and C. S. Yee. 1991. Road construction and maintenance. Influences of forest and rangeland management on Salmonid fishes and their habitats. *American Fisheries Society Special Publication* 19: 297-323

- Garant, D., I. A. Fleming, S. Einum, and L. Bernatchez. 2003. Alternative male life-history tactics as potential vehicles for speeding introgression of farm salmon traits into wild populations. *Ecol. Lett.* 6(6): 541-549
- Garman, G.C., and J.R. Moring. 1991. Initial effects of deforestation on physical characteristics of a boreal river. *Hydrobiologia* 209: 29-37
- Garside, E.T. 1973. Ultimate upper lethal temperature of Atlantic salmon *Salmo salar* L. *Can. J. Zool.* Vol. 51 898-900
- Gessel, S. P., and D. W. Cole. 1973. Nitrogen balances in forest ecosystems of the Pacific Northwest. *Soil Biology and Biochemistry* 5:19-34
- Gibbons, D.R., and E.O. Salo. 1973. An annotated bibliography of the effects of logging on fish of the western United States and Canada. U.S. Forest Service General Technical Report PNW-10
- Gibson, R. J. 1993. The Atlantic salmon in freshwater: Spawning, rearing and production. *Reviews in Fish Biology and Fisheries* 3(1): 39-73
- Giger, R.D. 1973. Streamflow requirements of salmonids. Oregon Wildlife Commission, Job Final Report, Project AFS-62-1, Portland, OR
- Gjedrem, T., H.M. Gjoen, and B. Gjerde. 1991. Genetic origin of Norwegian farmed Atlantic salmon. *Aquaculture* 98(1/3): 41-50
- Glebe, B.D. 1998. East Coast Salmon Aquaculture Breeding Programs: History and Future. DFO Canadian Stock Assessment Secretariat Research Document 98/157. Dept. of Fisheries and Oceans, Canada
- Godfrey, H. 1957. Feeding of eels in four New Brunswick salmon streams. *Fisheries Research Board of Canada.* 67:19-22
- Gorham, E. 1991. Northern peatlands; role in the carbon cycle and probable responses to climatic warming. *Ecol. Appl.* 1, 182-195
- Grant, J.W.A., S. O. Steingrímsson, E.R. Keeley, and R.A. Cunjak. 1998. Implications of territory size for the measurement and prediction of salmonid abundance in streams. *Can. J. Fish. Aquat. Sci.* 55(suppl. 1): 181-190
- Greene C. H. and A. J. Pershing. 2007. Climate Drives Sea Change. *Science Magazine.* Vol. 315
- Gregory, S. V., F. J. Swanson, W. A. McKee, and K. W. Cummins. 1991. An ecosystem perspective of riparian zones. *Bioscience* 41: 540-551
- Gregory, S. V., G. A. Lamberti, D. C. Emian, K. V. Koski, M. L. Murphy, and J. R. Sedell. 1987. Influence of forest practices on aquatic production. Pages 233-255

- In:* E. O. Salo and T. W. Cundy, editors. Streamside management: forestry and fishery interactions. Contribution No. 57. Institute of Forest Resources. University of Washington, Seattle, WA
- Gross, Mart R. 1998. One species with two biologies: Atlantic salmon (*Salmo salar*) in the wild and in aquaculture. *Can. J. Fish. Aquat. Sci.* 55 (S1): 131-144
- Grout, Douglas E. 2006. Interactions between striped bass (*Morone saxatilis*) rebuilding programs and the conservation of Atlantic salmon (*Salmo salar*) and other anadromous fish species in the USA. *ICES J. Marine Sci.* 63(7): 1346 – 1352
- Gustafson-Marjenan, K. I., and H. B. Dowse. 1983. Seasonal and diel patterns of emergence from the redd of Atlantic salmon (*Salmo salar*) fry. *Canadian Journal of Fisheries and Aquatic Sciences* 40: 813-817
- Gustafson-Greenwood, K. I., and J. R. Moring. 1991. Gravel compaction and permeabilities in redds of Atlantic salmon, *Salmo salar* L. *Aquaculture and Fisheries Management* 22: 537-540
- Haines, T. A. 1981. Acidic precipitation and its consequences for aquatic ecosystems: A Review. *Transactions of the American Fisheries Society.* 110: 669-707
- Haines, T. A. 1992. New England's rivers and Atlantic salmon. Pages 131-139 in R. H. Stroud, ed. *Stemming the tide of coastal fish habitat loss.* National Coalition for Marine Conservation, Savannah, GA.
- Haines, T.A., S.A. Norton, J.S. Kahl, C.W. Fay, and S.J. Pauwels. 1990. Intensive studies of stream fish populations in Maine. *Ecological Research Series.* U.S. Environmental Protection Agency. 354pp
- Halvorsen, M., and L. Jørgenson. 1996. Lake-use by juvenile Atlantic salmon (*Salmo salar* L.) and other salmonids in northern Norway. *Ecology of Freshwater Fish* 5(1): 28-36
- Halvorsen, M. & Svenning, M.-A. 2000. Growth of Atlantic salmon parr in fluvial and lacustrine habitats. *Journal of Fish Biology* **57**: 145–160.
- Hammill, M.O. and G.B. Stenson. 2000. Estimated prey consumption by harp seals (*Phoca groenlandica*), hooded seals (*Cystophora cristata*), grey seals (*Halichoerus grypus*) and harbour seals (*Phoca vitulina*) in Atlantic Canada. *Journal of Northwest Atlantic Fishery Science* 26:1-23
- Handeland, S.O., T. Jarvi, A. Ferno, and O. Stefansson. 1996. Osmotic stress antipredator behavior and mortality of Atlantic salmon (*Salmo salar*) smolts. *Can. J. Fish. Aqu. Sci.* 53(12): 2673-2680
- Hansen, L.P and P. Pethon. 1985. The food of Atlantic salmon, *Salmo salar* L., caught by long-line in northern Norwegian waters. *J. Fish Biol.* 26: 553-562

- Hansen, L.P. and B. Jonsson. 1989. Salmon ranching experiments in the River Imsa: effect of timing of Atlantic salmon (*Salmo salar*) smolt migration on survival to adults. *Aquaculture*. 82: 367-373
- Hansen, L.P. and T.P. Quinn. 1998. The marine phase of the Atlantic salmon (*Salmo salar*) life cycle, with comparisons to Pacific salmon. *Can. J. Fish. Aquat. Sci.* 55(S1): 104-118
- Hansen, L.P., and J.A. Jacobsen. 2000. Distribution and migration of Atlantic salmon, *Salmo salar* L., in the sea. *In: The Ocean Life of Atlantic Salmon: Environmental and Biological Factors Influencing Survival*. [ed. D. Mills] Ch. 7. Fishing News Books, Oxford
- Hansen, L.P., M. Holm, J.C. Holst, and J.A. Jacobsen. 2003. The ecology of post-smolts of Atlantic Salmon. *In: Salmon at the Edge*. [ed. D. Mills] p. 25-39. Blackwell Publishers, Oxford
- Hansen, L.P., N. Jonsson, B. Jonsson. 1993. Oceanic migration in homing Atlantic salmon. *Animal Behavior*. 45: 927- 940
- Hasbrouck, S. 1995. Maine Rivers and Streams. Geographical Digest Series. University of Maine
- Hasler, A.D. and A.T. Scholz. 1983. Olfactory Imprinting and Homing in Salmon. Springer-Verlag, Berlin, New York
- Hawryshyn, C. W. and F.I. Harosi. 1993. Spectral characteristics of visual pigments in rainbow trout (*Oncorhynchus mykiss*). *Vision Res.* 34: 1385-1392
- Hedger, R.D., J.J. Dodson, N.E. Bergeron, and F. Caron. 2005. Habitat selection by juvenile Atlantic salmon: the interaction between physical habitat and abundance. *Journal of Fish Biology* 67: 1054-1071
- Heede, B.H. 1980. Stream dynamics: an overview for land managers. U.S. Forest Service General Technical Report RM-72
- Heggenes, J. 1990. Habitat utilization and preferences in juvenile Atlantic salmon (*Salmo salar*) in streams. *Regulated Rivers. Research and Management* 5(4): 341-354
- Heggenes, J., J. Bagliniere, and R. Cunjak. 1999. Spatial niche variability for young Atlantic salmon (*Salmo salar*) and brown trout (*S. trutta*) in heterogeneous streams. *Ecol. Freshw. Fish* 8: 1-21
- Heintz, R.A., B.D. Nelson, J.H. Hudson, M. Larsen, L. Holland, and M. Wipfli. 2003. Marine Subsidies in Freshwater: Effects of Salmon Carcasses on Lipid Class and Fatty Acid Composition of Juvenile Coho Salmon. *Transactions of the American Fisheries Society*. 133(3): 559-567

- Heinz Center. 2002. Dam Removal: Science and Decision Making. The John Heinz III Center for Science, Economics, and the Environment. Washington, D.C.
- Heiser, D. W. and Jr. E.L. Finn. 1970. Observations of juvenile chum and pink salmon in marina and bulkheaded areas, Suppl. Progress Report. WDF, Olympia, WA.
- Hicks, B. J., J. D. Hall, P. A. Bisson, and J. R. Sedell. 1991. Response of salmonids to habitat changes. *In*: Book: Influences of forest and rangeland management on salmonid fishes and their habitats. American Fisheries Society. 19: 483-518
- Hill, M.T., W.S. Platts, and R.L. Beschta. 1991. Ecological and geomorphological concepts for instream and out-of-channel flow requirements. *Rivers* 2(3): 198-210
- Hiscock, M. J., D. A. Scruton, J. A. Brown, and C. J. Pennell. 2002a. Diel activity pattern of juvenile Atlantic salmon (*Salmo salar*) in early and late winter. *Hydrobiologia* 483: 161-165
- Hiscock, M.J., D.A. Scruton, J.A. Brown, and K.D. Clarke. 2002b. Winter movement of radio-tagged juvenile Atlantic salmon in Northeast Brook, Newfoundland. *Transactions of the American Fisheries Society* 131(3): 577-581
- Hislop, J.R.G. and R.G.J. Shelton. 1993. Marine predators and prey of Atlantic salmon (*Salmo salar* L.). p. 104 -118 in [ed: D..Mills] Salmon in the Sea and New Enhancement Strategies. Fishing News Books, Oxford.
- Hoar, W.S. 1988. The physiology of smolting salmon. *In*: W.S. Hoar and D.J. Randall, Editors, *Fish Physiology XIB*, Academic Press, New York. pp. 275-343
- Holm, M., I Huse, E. Waatevik, K. Doeving, J. Aure. 1982. Behavior of Atlantic salmon smolts during seaward migration. 1: Preliminary report on ultrasonic tracking in a Norwegian fjord system. ICES; Copenhagen (Denmark); ICES Council Meeting 1982. (Collected Papers) 17pp.
- Holm, M., J.C. Holst and L.P. Hansen. 2000. Spatial and temporal distribution of post-smolts of Atlantic salmon (*Salmo salar* L.) in the Norwegian Sea and adjacent waters. *ICES J. Marine Sci.* 57: 955-964
- Holst, J. C., P. Jacobsen, F. Nilsen, M. Holm, and J. Aure. 2003. Mortality of seaward-migrating post-smolts of Atlantic salmon due to salmon lice infection in Norwegian salmon stocks. Pages 136–157 *in* D. Mills, editor. *Salmon at the edge*. Blackwell Scientific Publications, Oxford, UK.
- Holst, J.C., L.P. Hansen and M. Holm. 1996. Observations of abundance, stock composition, body size and food of postsmolts of Atlantic salmon in the NE Atlantic during summer. *ICES CM* 1996/M: 4
- Hornbeck, J.W., R.S. Pierce, and C.A. Federer. 1970. Streamflow changes after forest clearing in New England. *Water Resources Research* 6: 1124-1132

- Hosmer, M.J., Stanley, J.G., and Hatch, R.W. 1979. Effects of hatchery procedures on later return of Atlantic salmon to rivers of Maine. *Progressive Fish Culturist*. 32: 115-119
- Huntsman, A. 1942. Death of salmon and trout with high temperature. *J. Fish. Res. Board Can.* 5: 485-501
- Hutchings, J.A. 1986. Lakeward migrations by juvenile Atlantic salmon, *Salmo salar*. *Canadian Journal of Fisheries and Aquatic Sciences*. 43(4): 732-741
- Hvidsten, N.A. and L.P. Hansen. 1988. Increased recapture rate of adult Atlantic salmon (*Salmo salar* L.) stocked as smolts at high water discharge. *J. Fish Bio.* 32(1): 153-154
- Hvidsten, N.A. and R.A. Lund. 1988. Predation on hatchery-reared and wild smolts of Atlantic salmon, *Salmo salar* L., in the estuary of river Orkla, Norway. *J. Fish. Bio.* 33: 121-126
- Hvidsten, N.A. Mokkelgjerd, P.I. 1987. Predation on salmon smolts, *Salmo salar* L., in the estuary of the river Suma, Norway. *J. Fish. Bio.* 30: 273-280
- Hyvarinen, P., P. Suuronen and T. Laaksonen. 2006. Short-term movement of wild and reared Atlantic salmon smolts in brackish water estuary – preliminary study. *Fish. Mgmt. Eco.* 13(6): 399-401
- Ibbotson, A.T., W.R.C. Beaumont, A. Pinder, S. Welton, M. Ladle. 2006. Diel migration patterns of Atlantic salmon smolts with particular reference to the absence of crepuscular migration. *Ecology of Freshwater Fish.* 15(4): 544-551
- IPCC (Intergovernmental Panel on Climate Change). 2001. *Climate Change 2001: The Scientific Basis. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change.* J.T. Houghton, Y. Ding, D.J. Griggs, M. Noguer, P.J. Van der Linden, X. Dai, K. Maskell, and C.A. Johnson, eds. Cambridge University Press. Cambridge, United Kingdom and New York, NY, USA. 881pp.
- Iwamoto, R.N., E.O. Salo, M.A. Madej, and R.L. McComas. 1978. Sediment and water quality: a review of the literature including a suggested approach for water quality criteria. U.S. Environmental Protection Agency, EPA Report 910/9-78-048, Washington, D.C.
- Jacobsen, J.A. and L.P. Hansen. 2000. Feeding Habits of Atlantic Salmon at Different Life Stages at Sea. Chapter 13 *In: The Ocean Life of Atlantic Salmon.* Ed: Derek Mills. Fishing News Books, Cronwall
- Jacobsen, J.A., and L.P. Hansen. 2001. The food of wild and escaped farmed Atlantic salmon, *Salmo salar* L., in the Northeast Atlantic. *ICES J. Marine Sci.* 58(4): 916-933

- Jago, C.H. and T.A. Haines. 1997. Changes in gill morphology of Atlantic salmon (*Salmo salar*) smolts due to addition of acid and aluminum to stream water. *Environmental Pollution*. 97(1-2): 137-146
- Jarp, J., and E. Karlsen. 1997. Infectious salmon anemia (ISA) risk factors in sea-cultured Atlantic salmon, *Salmo salar*. *Dis. Aquat. Org.* 28: 79-86
- Jarvi, T. 1989a. Synergistic effect on mortality in Atlantic salmon, *Salmo salar*, smolts caused by osmotic stress and presence of predators. *Enviro. Biol. Fishes.* 26: 149-152
- Jarvi, T. 1989b. The effect of osmotic stressors on the anti-predator behavior of Atlantic salmon smolts – a test of “maladaptive anti-predator behavior” hypothesis. *Nord J. Freshwater Res.* 65: 71-79
- Jarvi, T. 1990. Cumulative acute physiological stress in Atlantic salmon smolts; the effect of osmotic imbalance and the presence of predators. *Aquaculture* 89: 337-350
- Jenkinson, D.S., D.E. Adams, and A. Wild. 1991. Model estimates of CO₂ emissions from soil in response to global warming. *Nature* 351: 304-306
- Jensen, K., and E. Snekvik. 1972. Low pH levels wipe out salmon and trout populations in southernmost Norway. *Ambio* 1: 223-225
- Johnsen, R.I., Grahl-Nielsen, O., and Lunestad, B.T. 1993. Environmental distribution of organic waste from a marine fish farm. *Aquaculture* 118: 229-244
- Johnson, D.W. and D.A. Webster. 1977. Avoidance of Low pH in Selection of Spawning Sites by Brook Trout (*Salvelinus fontinalis*). *Journal of the Fisheries Research Board of Canada* 34: 2215-2218
- Johnson, K. and J.S. Kahl. 2005. A systematic survey of water chemistry for Downeast area rivers. Project final report to Maine Atlantic Salmon Commission.
- Johnston, C. E., and Saunders, R.L. 1981. Parr-smolt transformation of yearling Atlantic salmon (*Salmo salar*) at several rearing temperatures. *Can. J. Fish. Aquat. Sci.* 38: 1189-1198
- Jones, J.W. 1959. Some parasites and diseases of salmon. *In: The salmon*. Harper and Brothers, New York, NY. Pages 159-167
- Jonsson, B. 1997. A review of ecological and behavioural interactions between cultured and wild Atlantic salmon. *ICES Journal of Marine Science.* 54(6): 1031-1039
- Jonsson, B. and N. Jonsson. 2004a. Factors affecting marine production of Atlantic salmon (*Salmo salar*). *Can. J. Fish. Aquat. Sci.* 61: 2369-2383

- Jonsson, N. and B. Jonsson. 2004b. Size and age at maturity of Atlantic salmon correlate with the North Atlantic Oscillation Index (NAOI). *J. Fish. Biol.* 64: 241-247
- Jonsson, N., B. Jonsson, and L.P. Hansen. 1990. Partial segregation in the timing of migration of Atlantic salmon of different ages. *Animal Behaviour*. 40(2): 313-321
- Jonsson, N., Jonsson, B., and Hansen, L.P. 2003. Marine survival and growth of wild and released hatchery reared Atlantic salmon. *J. Appl. Ecol.* 40: 900-911
- Jonsson, N., L.P. Hansen, and B. Jonsson. 1991. Variation in age, size and repeat spawning of adults Atlantic salmon in relation to river discharge. *J. Anim. Ecol.* 60: 937-947
- Jordan, R. M. and Beland, K. F.. 1981. Atlantic Sea Run Salmon Commission. Augusta, Maine
- Juanes, F., S. Gephard, and K. F. Beland. 2004. Long-term changes in migration timing of adult Atlantic salmon (*Salmo salar*) at the southern edge of the species distribution. *Can. J. Fish. Aquat. Sci.* 61: 2392-2400
- Kalleberg, H. 1958. Observations in a stream tank of territoriality and competition in juvenile salmon and trout (*Salmo salar* L. and *S. trutta* L.). *Rep. Inst. Freshw. Res. Drottningholm* 39: 55-98
- Kallio-nyberg, I., E. Jutila, I. Saloniemi and E. Jokikokko. 2004. Association between environmental factors, smolt size and survival of wild and reared Atlantic salmon from the Simojoki River in the Baltic Sea. *J. Fish Bio.* 65(1): 122
- Kallio-Nyberg, Irma, Heikki Peltonen and Hannu Rita. 1999. Effects of stock-specific and environmental factors on the feeding migration of Atlantic salmon (*Salmo salar*) in the Baltic Sea. *Can. J. Fish. Aquat. Sci.* 56(5): 853-861
- Karr, J. R. 1991. Biological integrity: a long-neglected aspect of water resource management. *Ecological Applications* 1: 66-84
- Kazakov, R.V., and Khalyapina, L.M. 1981. Oxygen consumption of adult Atlantic salmon (*Salmo salar* L.) males and females in fish culture. *Aquaculture* 25: 289-292
- Keeley, E. R. and Grant, W.A. 1995. Allometric and environmental correlates of territory size in juvenile Atlantic salmon (*Salmo salar*). *Canadian Journal of Fisheries and Aquatic Sciences* 52: 186-196
- Keeley, E.R. and J.W.A. Grant. 1997. Allometry of diet selectivity in juvenile Atlantic salmon (*Salmo salar*). *Can. J. Fish. Aquat. Sci.* 54: 1894-1902

- Kemp, S. J. and J. R. Spotila. 1997. Effects of urbanization on brown trout (*Salmo trutta*), other fishes and macroinvertebrates in Valley Creek, Valley Forge, Pennsylvania. *American Midland Naturalist*. 138(1): 55-68
- Kennedy, M.K., and J.E. Greer. 1988. Predation by cormorants (*Phalacrocorax carbo L.*), on the salmonid populations of an Irish River. *Aqua. and Fish. Mgmt.* 19(2): 159-170
- Kircheis, F.W. 2004. Sea Lamprey (*Petromyzon marinus*). Carmel, ME. 21pp. and appendices
- Klemetson, A., P.A. Amundsen, J.B. Dempson, B. Jonsson, N. Jonsson, M.F. O'Connell, and E. Mortensen. 2003. Atlantic salmon *Salmon salar* (L.), brown trout *Salmo trutta* (L.) and Arctic charr *Salvelinus alpinus* (L.): a review of aspects of their life histories. *Ecology of Freshwater Fish* 12(1): 1-59
- Kramer, J.R. 1986. Aluminum geochemistry. Aluminum in the Canadian Environment (M. Havas and J.F. Jaworski, eds.) National Research Council of Canada, Ottawa, NRCC No. 24759, 25pp.
- Krause, A.E., K.A. Frank, D.M. Mason, R.E. Ulanowicz, and W.W. Taylor. 2003. Compartments revealed in food-web structure. *Nature* Vol. 426(20): 282-285
- Kroglund F. and M. Staurnes. 1999. Water quality requirements of smolting Atlantic salmon (*salmo salar*) in limed acid rivers. *Can. J. Fish. Aquat. Sci.* 56: 2078-2086
- Kullberg A., K.H. Bishop, A. Hargeby, M. Jansson and R.C. Peterson , Jr.. 1993. The ecological significance of dissolved organic carbon in acidified waters. *Ambio* 22(5): 331-337
- LaBar, G.W., J.D. McCleave, and S.M. Fried. 1978. Seaward migration of hatchery reared Atlantic salmon (*Salmo salar*) smolts in the Penobscot River estuary, Maine: open-water movements. *Journal du Conseil. International Council for the Exploration of the Sea* 38(2): 257-269
- Lacroix G.L., Paul McCurdy, Derek Knox. 2004. Migration of Atlantic Salmon Postsmolts in Relation to Habitat Use in a Coastal System. *Trans. Am. Fish. Soc.* 133(6): 1455-1471
- Lacroix, G.L. and D.R. Townsend. 1987. Responses of juvenile Atlantic salmon (*Salmo salar*) to episodic increases in acidity of Nova Scotia rivers. *Canadian Journal of Fisheries and Aquatic Sciences*. 44(8): 1475-1484
- Lacroix, G.L. and McCurdy, P. 1996. Migratory behavior of post-smolt Atlantic salmon during initial stages of seaward migration. *J. Fish Biol.* 49: 1086-1101

- Lacroix, G.L., D. Knox and M.J. W. Stokesbury. 2005. Survival and behavior of postsmolt Atlantic salmon in coastal habitat with extreme tides. *J. Fish Bio.* 66(2): 485-498
- Lacroix, Gilles L. and Derek Knox. 2005. Distribution of Atlantic salmon (*Salmo salar*) postsmolts of different origins in the Bay of Fundy and Gulf of Maine and evaluation of factors affecting migration, growth and survival. *Can. J. Fish. Aquat. Sci.* 62(6): 1363-1376
- Lacroix, Gilles L; McCurdy, Paul; Knox, Derek 2004. Migration of Atlantic Salmon Postsmolts in Relation to Habitat Use in a Coastal System. *Transactions of the American Fisheries Society [Trans. Am. Fish. Soc.]*. Vol. 133(6): 1455-1471
- Larson, K., and C. Moehl. 1990. Fish entrainment by dredges in Grays Harbor, Washington. In: *Effects of Dredging on anadromous Pacific Coast Fishes*. C.A. Simenstad. Washington Sea Grant Program, University of Washington
- Larsson, P.O. 1977. The importance of time and place of release of salmon and sea trout on the results of stocking. *ICES CO 1977/M: 42*. 10pp.
- Larsson, P.O. 1985. Predation on migrating smolt as a regulating factor in Baltic salmon, *Salmo salar* L., populations. *J. Fish Bio.* 26(4): 391-397
- Lear, W.H. 1972. Food and feeding of Atlantic salmon in coastal areas and over oceanic depths. *Res. Bull. Int. Comm. NW Atlantic Fish.* 9: 27-39
- Lear, W.H. 1980. Food of Atlantic salmon in the West Greenland – Labrador Sea area. *Rapp. P-V. Reun. Cons. Int. Explor. Mer.* 176: 55- 59
- Legault, C.M. 2004. Salmon PVA: a population viability analysis model for Atlantic salmon in the Maine Distinct Population Segment. Ref. Doc. 04-02. Woods Hole, MA. 88pp.
- Leim, A.H. and Scott W.B. 1966. Fishes of the Atlantic coast of Canada. Fisheries Research Board of Canada: 21-22
- Leivestad, H. and I.P. Muniz. 1976. Fish kill at low pH in a Norwegian River. *Nature.* 259: 391-392
- Leivestad, H., G. Hendry, I.P. Muniz, and E. Snekvik. 1976. Effects of acid precipitation on freshwater organisms. 87-111 *In: Impact of acid precipitation on forest and freshwater ecosystems in Norway* (ed. F.W. Brackke). Research Report 6/76, SNSF Project, Oslo, Norway
- Leopold, L.B. 1968. Hydrology for urban land planning: a guidebook on the hydrologic effects of land use. Reston (VA): US Geological Survey. Circular nr 554.

- Leopold, L.B., and W.W. Emmett. 1983. Bedload movement and its relation to scour. Pages 640-649 *In*: C.M. Elliott, editor. River Meandering. Proceedings from the Conference on Rivers. New Orleans, Louisiana. American Society of Civil Engineers Waterways, Port, Coastal and Ocean Section.
- LePage, C.A., M.E. Foley, and W.B. Thompson. 1991. Mining in Maine: Past, Present, and Future. Maine Geological Survey Open-File 91-7. Department of Conservation, Maine Geological Survey, State of Maine.
<http://www.maine.gov/doc/nrimc/mgs/explore/mining/minemaine.htm>
- Levings, C.D. 1994. Feeding behavior of juvenile salmon and significance of habitat during estuary and early sea phase. *Nordic J. of Freshwater Research*. 69: 7-16
- Li, H. W., C. B. Schreck, and R. A. Tubb. 1984. Comparison of habitats near spur dikes, continuous revetments, and natural banks for larval, juvenile, and adult fishes of the Willamette River. Water Resources Research Institute, Oregon State University, Corvallis, Oregon
- Ludwig, M., D. Rusanowsky, and C. Johnson-Hughes. 1997. The impact of installation and use of a pier and dock assembly on eelgrass (*Zostera marina*) at Star Island, Montauk NY: Kalikow Dock Study., NMFS. USFWS
- Lundqvist, H. 1980. Influence of photoperiod on growth in Baltic salmon parr (*Salmo salar* L.) with special reference to the effect of precocious sexual maturation. *Canadian Journal of Zoology*. 58(5): 940-944
- Lura, H., and H. Sægrov. 1993. Timing of spawning in cultured and wild Atlantic salmon (*Salmo salar*) and brown trout (*Salmo trutta*) in the river Vosso, Norway. *Ecol. Freshwater Fish* 2(4):167-172
- Madsen, S.S., A.B. Mathiesen and B. Korsgaard. 1997. Effects of 17 β – estradiol and 4-nonylphenol on smoltification and vitellogenesis in Atlantic salmon (*Salmo salar*). *Fish Physiol. Biochem.* 17: 303-312
- Magee, J.A., M. Obedzinski, S.D. McCormick, and J.F. Kocik. 2003. Effects of episodic acidification on Atlantic salmon (*Salmo salar*) smolts. *Canadian Journal of Fisheries and Aquatic Sciences* 60(2): 214-221
- Magee, J.A., T.A. Haines, J.F. Kocik, K.F. Beland, and S.D. McCormick. 2001. Effects of acidity and aluminum on the physiology and migratory behaviour of Atlantic salmon smolts in Maine, USA. *Water, Air, and Soil Pollution*. 130(1-4): 881-886
- Maine Board of Pesticide Control. 2006. Common ME Agricultural Pesticides with Environmental Fate Information and 2006 Drinking Water Advisory Levels. United States Department of Agriculture's Natural Resource Conservation Service. USDA/NRCS National Water and Climate Center, Amherst, MA.
http://www.maine.gov/agriculture/pesticides/water/leaching_potential.htm

- Maine State Planning Office. 2005. Maine County Economic Forecast. Maine State Planning Office, Augusta, ME
- Marschall, E.A., T.P. Quinn, D.A. Roff, J. A. Hutchings, N.B. Metcalfe, T.A. Bakke, R.L.Saunders and N.LeRoy Poff. 1988. A Framework for understanding Atlantic salmon (*Salmo salar*) life history. Can. J. Fish. Aquat. Sci. 55(Suppl. 1): 48-58.
- MASTF (Maine Atlantic Salmon Task Force). 1997. Atlantic Salmon Conservation Plan for Seven Rivers. State of Maine, Augusta, ME. 435pp.
- Matthews, M.A., W.R. Poole, M.G. Dillane, K.F. Whelan. 1997. Juvenile recruitment and smolt output of brown trout (*Salmo trutta* L.) and Atlantic salmon (*Salmo salar* L.) from a lacustrine system in western Ireland. Fisheries Research. 31: 19-37
- McCabe, G.T. 1997. Fishes in bottom habitats in six flowland disposal areas of the lower Columbia River, 1996-97. Coastal Zone and Estuarine Studies Division. Northwest Fisheries Science Center, National Marine Fisheries Service
- McCarthy, I.D. and D.R. Houlihan. 1997. The effect of temperature on protein metabolism in fish: The possible consequences for wild Atlantic salmon (*Salmo salar* L.) stocks in Europe as a result of global warming. Pp.51-57 In: Global Warming: Implications for freshwater and marine fish (eds. C.M. Wood and D.G. McDonald). Cambridge Universtiy Press, Cambridge, United Kingdom.
- McCleave, J.D., 1978. Rythmic aspects of estuarine migration of hatchery-reared Atlantic salmon, *Salmo salar*, smolts. J. Fish Biol. 12: 559-570
- McCormick S.D., L.P. Hansen, T. Quinn, and R. Saunders. 1998. Movement, migration, and smolting of Atlantic salmon (*Salmo salar*). Can. J. Fish. Aquat. Sci. 55(Suppl. 1): 77-92
- McCormick S.D., R.A. Cunjak, B. Dempson, M. O'Dea, J. Carey. 1999. Temperature-related loss of smolt characteristics in Atlantic salmon (*Salmo salar*) in the wild. Can. J. Fish Aquat. Sci. 56: 1649-1658
- McCormick, S.D. and R.L. Saunders. 1987. Preparatory physiological adaptations for marine life of salmonids: Osmoregulation, growth, and metabolism. Common Strategies of Anadromous and Catadromous Fishes. Proceedings of an International Symposium held in Boston, Massachusetts, USA, March 9-13, 1986. American Fisheries Society Symposium. 1: 211-229
- McCormick, S.D., J.M. Shrimpton, S. Moriyama, and B.T. Bjornsson. 2002. Effects of an advanced temperature cycle on smolt development and endocrinology indicate that temperature is not a zeitgeber for smolting in Atlantic salmon. Journal of Experimental Biology. 205: 3553-3560

- McElravy E. P., G. A. Lamberti, V. H. Resh. 1989. Year-to-year variation in the aquatic macroinvertebrate fauna of a Northern California stream. *Journal of the North American Benthological Society*. Vol. 8, No. 1: 51-63
- McGinnity, P., A. Ferguson, N. Baker, D. Cotter, T. Cross, D. Crooke, R. Hynes, B.O’Hea, N.O’Maoileidigh, P. Prodohl, and G. Rogan. 2003. A two-generation experiment comparing the fitness and life history traits of native, ranched, non-native, farmed and ‘hybrid’ Atlantic salmon under natural conditions. *In: Salmon at the Edge*. [ed: D. Mills]. Chpt. 12 . Blackwell Publishing, Oxford
- McGinnity, P., C. Stone, J.B. Taggart, D. Cooke, D. Cotter, R. Hynes, C. McCamley, T. Cross, and A. Ferguson. 1997. Genetic impact of escaped farmed Atlantic salmon (*Salmo salar* L.) on native populations: Use of DNA profiling to assess freshwater performance of wild, farmed, and hybrid progeny in a natural river environment. *ICES J. Mar. Sci.* 54(6): 998–1008
- McGraw, K. and D. Armstrong. 1990. Fish entrainment by dredges in Grays Harbor, Washington. In: C.A. Simenstad (ed). *Effects of dredging on anadromous Pacific Coast Fishes*. Washington Sea Grant Program, University of Washington
- McKenna, M.G., and F. Duerr. 1976. Effects of ambient water pH on the gills of *Ictalura melas* Raf. *Am. Zool.* 16:224
- McLaughlin, E. and A. Knight. 1987. Habitat criteria for Atlantic salmon. Special Report, U.S. Fish and Wildlife Service, Laconia, New Hampshire. 18pp.
- McVicar, A.H. 1998. Disease and parasite implications of the coexistence of wild and cultured Atlantic salmon populations. *ICES J. Marine. Sci.* 54(6): 1093-1103
- McWilliams, W.H., B.J. Butler, L.E. Caldwell, D.M. Griffith, M.L. Hoppus, K.M. Laustsen, A.J. Lister, T.W. Lister, J.W. Metzler, R.S. Morin. S.A. Sader, L.B. Stewart, J.R. Steinman, J. Westfall, D.A. Williams, A. Whitman, and C.W. Woodall. 2005. *The Forests of Maine: 2003*. Resource Bulletin NE-164. U.S. Department of Agriculture, Forest Service, Northeastern Research Station. Newtown Square, PA.
- MEGIS (Maine Office of Geographic Information Systems) 2006. impounds. Maine GIS. SDE server; Internet Data Catalog. Maine Office of Geographic Information Systems (MEGIS), Augusta ME. Accessed 12/2007.
<http://megis.maine.gov/catalog/>
- Meister, A.L. and F.J. Gramlich. 1967. Cormorant predation on tagged Atlantic salmon smolts. Final report of the 1966-67 Cormorant- Salmon Smolt Study. Atlantic Sea Run Salmon Commission, Orono, Maine
- Meister, A.L. 1958. *The Atlantic salmon (Salmo salar) of Cove Brook, Winterport, Maine*. M.S. Thesis. University of Maine. Orono, ME. 151pp.

- Middlemass, S.J., J.D. Armstrong and P.M. Thompson. 2003. The significance of marine mammal predation on salmon and sea trout. Chpt 5. *In: Salmon at the Edge* [ed: D. Mills]. Blackwell Science, Oxford
- Milligan, C. L. & Wood, C. M. 1982. Disturbances in haematology, fluid volume distribution and circulatory function associated with low environmental pH in the rainbow trout, *Salmo gairdneri*. *Journal of Experimental Biology* 99: 397-415
- Mills, D.H. 1964. The Ecology of the Young Stages of the Atlantic Salmon in the River Bran, Ross-shire. Department of Agriculture and Fisheries for Scotland. Freshwater and Salmon Fisheries Research 32. Edinburgh: Her Majesty's Stationery Office.
- Mills, L.S., M.E. Soule, and D.F. Doak. 1993. The Keystone-Species Concept in Ecology and Conservation. *Bioscience*. 43(4): 219-224
- Montevecchi, W.A, D.K. Cairns, R.A. Myers. 2002. Predation on marine-phase Atlantic salmon (*Salmo salar*) by gannets (*Morus bassanus*) in the Northwest Atlantic. *Can. J. Fish. Aquat. Sci.* 59(4): 602-612
- Montevecchi, W.A., D.K. Cairns, V.L. Birt. 1988. Migration of postsmolt Atlantic salmon, *Salmo salar*, off northeastern Newfoundland, as inferred by tag recoveries in a seabird colony. *Can J. Fish Aquat. Sci.* 45: 568-571
- Montgomery, D. R., and J. M. Buffington. 1993. Channel classification, prediction of channel response, and assessment of channel condition. TFW-SH10-93-002, Prepared for the SHAMW committee of the Washington State Timber Fish & Wildlife agreement. Timber Fish & Wildlife, Seattle, Washington.
- Moore, A. and C.P. Waring. 1996. Sublethal Effects of the Pesticide Diazinon on Olfactory Function in Mature Male Atlantic Salmon Parr. *J. Fish. Biol.* 48: 758-775
- Moore, A., E.C.E. Potter, N.J. Milner, S. Bamber. 1995. The migratory behavior of wild Atlantic salmon (*Salmo salar*) smolts in the estuary of the River Conway. North Wales. *Can J. Fish. Aquat. Sci.* 52: 1923-1935
- Morantz, D., R. Sweeney, C. Shirvell, and D. Longard. 1987. Selection of microhabitat in summer by juvenile Atlantic salmon (*Salmo salar*). *Can. J. Fish. Aquat. Sci.* 44: 120-129
- Moring, J. R. 1975. The Alsea Watershed Study: effects of logging on the aquatic resources of three headwater streams of the Alsea River, Oregon. Part II- changes in environmental conditions. Oregon Department of Fish and Wildlife, Research Report 9.
- Moring, J. R. and K. Finlayson. 1996. Relationship between land use activities and Atlantic salmon (*Salmo salar*) habitat: A literature review. Final Report to: The

- National Council of the Paper Industry for Air and Stream Improvement, Inc.
University of Maine, Orono
- Morisawa, M. 1968. Streams: Their Dynamics and Morphology. New York: McGraw-Hill.
- Morse C. and S. Kahl. 2003. Measuring the impact of development on Maine surface waters. The University of Maine – Senator George J. Mitchell Center for Environmental and Watershed Research. UMaine.edu/WaterResearch
- Morse, C.C. 2001. The Response of First and Second Order Streams to Urban Land-Use in Maine, U.S.A. The Graduate School, University of Maine, Orono, ME
- Mortimer, C.H. 1956. The oxygen content of air-saturated fresh waters, and aids in calculating percentage saturation. Intern. Assoc. Theoret. Appl. Commun. No 6.
- Moyle, P.B. 1976. Fish introductions in California: history and impact on native fishes. Biological Conservation 9:101-118
- Mulvihill, E. L., C. A. Francisco, J. B. Glad, K. B. Kaster, and R. E. Wilson. 1980. Biological impacts of minor shoreline structures on the coastal environment: State of the art review. FWS/OBS-77/51, 2 vol. U.S. Fish and Wildlife Service, Biological Services Program
- Murphy, M. L. 1995. Forestry impacts on freshwater habitat of anadromous salmonids in the Pacific Northwest and Alaska – requirements for protection and restoration. NOAA Coastal Ocean Program Decision Analysis Series No. 7. NOAA Coastal Ocean Office, Silver Spring, MD. 156 pp.
- Murphy, M. L., and W. R. Meehan. 1991. Stream ecosystems. In Book: Influences of forest and rangeland management on salmonid fishes and their habitats. American Fisheries Society Special Publication. 19: 17-46
- Myers, R. D. 1993. Slope stabilization and erosion control using vegetation: A manual of practice for coastal property owners. Olympia: Shorelands and Coastal Zone Management Program/Washington Department of Ecology
- National Research Council of the National Academies. 2003. Atlantic Salmon in Maine. The National Academies Press. Washington, D.C.
- Nelson, Marcy L., James R. Gilbert, and Kevin J. Boyle. 2006. The influence of siting and deterrence methods on seal predation at Atlantic salmon (*Salmo salar*) farms in Maine, 2001 – 2003. Can. J. Fish. Aquat. Sci. 63(8): 1710-1721
- Nelson, R.L., M.L. McHenry, and W.S. Platts. 1991. Mining. American Fisheries Society Special Publication 19:425-457

- Nemeth, R. S. 1989. "The photobehavioral responses of juvenile chinook and coho salmon to strobe and mercury lights." M.Sci. Thesis. University of Washington, Seattle, WA
- Newcomb, C.P. and T.O.T. Jensen. 1996. Channel Suspended Sediment and Fisheries: A synthesis for quantitative assessment of risk and impact. North American Journal of Fisheries Management 16(4): 693-716
- Nightingale, B. and C.A. Simenstad. 2001a. Dredging Activities: Marine Issues. Overwater Whitepaper prepared for Washington State Transportation Commission, Department of Transportation and in cooperation with U.S. Department of Transportation, Federal Highway Administration. Research Project T1803, Task 35. 182pp.
- Nightingale, B. and C.A. Simenstad. 2001b. Overwater Structures: Marine Issues. Overwater Whitepaper prepared for Washington State Transportation Commission, Department of Transportation and in cooperation with U.S. Department of Transportation, Federal Highway Administration. Research Project T1803, Task 35. 181pp.
- Nislow, K.H. J.D. Armstrong, and S. McKelvey. 2004. Phosphorus flux due to Atlantic salmon (*Salmo salar*) in an oligotrophic upland stream: effects of managements and demography. Can. J. Fish Aquat. Sci. 61: 2401-2410
- Nislow, K.H., C.L. Folt, and D.L. Parrish. 1999. Favorable foraging locations for young Atlantic salmon: application to habitat and population restoration. Ecological Applications. 9(3): 1085-1099
- NMFS (National Marine Fisheries Service). 1996. Making Endangered Species Act Determinations of Effect for Individual or Grouped Actions at the Watershed Scale. National Marine Fisheries Service, Environmental Services Division, Habitat Conservation Branch. 32pp
- NMFS (National Marine Fisheries Service). 2005. Salmon at the River's End: The Role of the Estuary in the Decline and Recovery of Columbia River Salmon. NOAA Technical Memorandum NMFS-NWFSC-68. 279pp.
- NMFS and FWS (National Marine Fisheries Service) and (United States Fish and Wildlife Service). 1999. Review of the status of anadromous Atlantic salmon (*Salmo salar*) under the US Endangered Species Act. National Marine Fisheries Service, Silverspring, MD. 230pp
- NMFS and FWS (National Marine Fisheries Service) and (United States Fish and Wildlife Service). 2005. Final Recovery Plan for the Gulf of Maine Distinct Population Segment of Atlantic Salmon (*Salmo salar*). National Marine Fisheries Service, Silverspring, MD. 325pp.

- NMFS and FWS (National Marine Fisheries Service) and (United States Fish and Wildlife Service). 2004. Draft Recovery Plan for the Gulf of Maine Distinct Population Segment of Atlantic Salmon (*Salmo salar*). National Marine Fisheries Service, Silver Spring, MD. 239 pages.
- Nolan, D.T., P. Reilly and S.E. Wendelaar Bonga. 1999. Infection with low numbers of the sea louse *Lepeophtheirus salmonis* induces stress-related effects in postsmolt Atlantic salmon (*Salmo salar*). *Can. J. Fish. Aquat. Sci.* 56(6): 947-959
- NEFA (North East State Foresters Association). 2007. The Economic Importance and Wood Flows from Maine's Forests, 2007. www.nefainfo.org
- Norris, L. A., H. W. Lorz and S. V. Gregory. 1991. Forest Chemicals *In: Influences of Forest and Rangeland Management of Salmonid Fishes and Their Habitats*. American Fisheries Society Special Publication 19:207-296
- Novalles-Flamarique, I. and C.W. Hawryshyn. 1996. Retinal development and visual sensitivity of young Pacific sockeye salmon (*Oncorhynchus nerka*). *J. Exp. Biol.* 199: 869-882
- NRC (National Research Council). 1995. Beach nourishment and protection. National Academy Press, Washington, D.C.
- NRC (National Research Council). 1996. Upstream: Salmon and Society in the Pacific Northwest. National Academy Press. Washington, D.C. 418pp. and appendices.
- NRC (National Research Council). 2004. Atlantic Salmon in Maine. National Academy Press. Washington, D.C. 304pp.
- O'Hara F. and J. Benson. 1997. The cost of sprawl. 010-07B-2906-012. October, 1991. Executive Department - Maine State Planning Office, Augusta, ME
- Omernik, J. and A. Kinney. 1985. Total alkalinity of surface waters: A map of the New England and New York region, U.S. Environmental Protection Agency, Washington D. C., EPA-600/D-84-216.
- Osterdahl, L. 1969. The smolt run of a small Swedish river. *In: Symposium of salmon and trout in streams*. Ed. T.G. Northcote. University of British Columbia, Vancouver, British Columbia, Canada.
- Paine, R.T. 1969. A note on trophic complexity and community stability. *Am. Nat.* 103: 91-93
- Pentec Environmental. 1997. Movement of juvenile salmon through industrialized areas of Everett Harbor, Pentec Environmental, Edmonds, WA
- Penttila, D. and M. Aguero. 1978. Fish usage of Birch Bay Village Marina, Whatcom County WA in 1976, Wash. Dept. Fish Prog. Rep. No. 39. WDF.

- Penttila, Dan and D. Doty. 1990. Results of 1989 eelgrass shading studies in Puget Sound, Progress Report Draft. WDFW Marine Fish Habitat Investigations Division
- Penttila, D. E. 2000. Impacts of overhanging shading vegetation on egg survival for summerspawning surf smelt, *Hypomesus*, on upper intertidal beaches in Northern Puget Sound, Washington. Marine Resources Division, Washington Department of Fish and Wildlife, Olympia, Washington
- Pepper, V.A. 1976. Lacustrine nursery areas for Atlantic salmon in Insular Newfoundland. Fisheries and Marine Service Technical Report 671. xiii+61 pp.
- Pepper, V.A., N.P. Oliver, R. Blunden. 1984. Lake surveys and biological potential for natural lacustrine rearing of juvenile Atlantic salmon (*Salmo salar*) in Newfoundland. Canadian Technical Report of Fisheries and Aquatic Sciences 1295. iv+ 72 pp.
- Peterson, R. H., P. G. Daye, and J. L. Metcalfe. 1980. Inhibition of Atlantic salmon (*Salmo salar*) hatching at low pH. Can. J. Fish. Aquat. Sci. 37: 770-774
- Peterson, R. H.. 1978. Physical characteristics of Atlantic salmon spawning gravel in some New Brunswick streams. Fish. Mar. Serv. Tech. Rep. No. 785. iv+28 pp.
- Peterson, R.H., R.A. Bourbonniere, G.L. Lacroix, D.J. Martin-Robichaud, P. Takats, and G. Brun. 1989. Responses of Atlantic salmon (*Salmo salar*) alevins to dissolved organic carbon and dissolved aluminum at low pH. Water Air and Soil Pollution. 46(1-4): 399-413
- Peterson, R.H., Spinney, H.C.E., and A. Sreedharan. 1977. Development of Atlantic Salmon (*Salmo salar*) Eggs and Alevins Under Varied Temperature Regimes. J. Fish. Res. Board Can. 34: 31-43
- Phillips, R.W., R.L. Lantz, E.W. Claire, and J.R. Moring. 1975. Some effects of gravel mixtures on emergence of coho salmon and steelhead trout fry. Transactions of the American Fisheries Society. 104(3): 461-466
- Platts, W. S.. 1991. Livestock grazing. In: Book: Influences of forest and rangeland management on salmonid fishes and their habitats. American Fisheries Society Special Publication 19: 389-423
- Platts, W.S. 1979. Relationships among stream order, fish populations, and aquatic geomorphology in an Idaho river drainage. Fisheries 4: 5-9
- Poff, N.L., J.D. Allan, M.B. Bain, J.R. Karr, K.L. Prestegard, B.D. Richter, R.E. Sparks, and J.C. Stromberg. 1997. The Natural Flow Regime. Bioscience, 47(11): 769-784

- Poston, T. 2001. Treated Wood Issues Associated with Over-water Structures in Marine and Freshwater Environments. White Paper Prepared for Washington Department of Fish and Wildlife, Washington Department of Ecology, and Washington Department of Transportation, Olympia, WA.
- Potter, E.C.E. 1988. Movements of Atlantic salmon, *Salmo salar* L., in an estuary in South-west England. J. Fish Biol. 33(Suppl. A): 153-159
- Power, G. and G. Shooner. 1966. Juvenile salmon in the estuary and lower Nabisipi River and some results of tagging. Journal of the Fisheries Research Board of Canada. 23: 947-961
- Puckett, K. J. and J.J. Anderson. 1987. Behavioral responses of juvenile salmonids to strobe and mercury lights. FRI-UW-8717. UW Fish Research Institute, Seattle WA
- Randall, R. G. 1982. Emergence, population densities, and growth of salmon and trout fry in two New Brunswick streams. Canadian Journal of Zoology 60(10): 2239-2244
- Ratte, L. D. 1985. Under-pier ecology of juvenile Pacific salmon (*Oncorhynchus* spp.) in Commencement Bay, Washington. University of Washington
- Reddin, D. G. and W.M. Shearer. 1987. Sea-surface temperature and distribution of Atlantic salmon in the Northwest Atlantic Ocean. American Fisheries Society Symposium.
- Reddin, D.G and K.D. Friedland. 1993. Marine environmental factors influencing the movement and survival of Atlantic salmon. pages 70-103. *In*: Mills, E.D. 1993. Salmon in the sea. Fishing News Books, Blackwell Scientific, Cambridge, MA.
- Reddin, D.G and P.B. Short. 1991. Postsmolt Atlantic salmon (*Salmo salar*) in the Labrador Sea. Can. J. Fish Aquat. Sci. 48: 2-6
- Reddin, D.G. 1985. Atlantic salmon (*Salmo salar*) on and east of Grand Bank. J. Northwest. Atlnt. Fish. Sci. 6: 157-164
- Reddin, D.G. 1988. Ocean life of Atlantic salmon (*Salmo salar* L.) in the Northwest Atlantic. p. 483-511. *In*: D. Mills and D. Piggins [eds.] Atlantic Salmon: Planning for the Future. Proceedings of the 3rd International Atlantic Salmon symposium.
- Reddin, D.G., J. Helbig, A. Thomas, B.G. Whitehouse and K.D. Friedland. 1997. Survival of Atlantic salmon (*Salmo salar* L.) related to marine climate. *In*: Wild Atlantic Salmon: New Challenges – New Techniques. Proceedings of the Fifth Int. Atlantic Salmon Symposium, Galway, Ireland

- Reddin, D.G., D.E. Standbury, and P.B. Short. 1988. Continent of origin of Atlantic salmon (*Salmo salar* L.) at West Greenland. *J. Cons. Int. Explor. Mer.* 44: 180-188.
- Reid, S.D., D.G. McDonald, and C.M. Wood. 1997. Interactive effects of temperature and pollutant stress. C.M. Wood and D.G. McDonald eds. Cambridge University Press, Cambridge, United Kingdom. Pages 325-339
- Reid, S.D., T.K. Linton, J.J. Dockray, D.G. McDonald, and C.M. Wood. 1998. Effects of chronic sublethal ammonia and a simulated summer global warming scenario: Protein synthesis in juvenile rainbow trout (*Oncorhynchus mykiss*). *Canadian Journal of Fisheries and Aquatic Sciences* 55(6): 1534-1544.
- Resh C. H., A. V. Brown, A. P. Covich, M. E. Gurtz, H. W. Li, G. W. Minshall, S. R. Reice, A. L. Sheldon, J. B. Wallace, R. C. Wissmar. 1988. The role of disturbance in stream ecology. *Journal of the North American Benthological Society.* 7(4): 433-455
- Reynolds, B., and N. Fenner. 2001. Export of organic carbon from peat soils. *Nature.* 412: 785-786
- Rikardsen, A.H., M. Hauglandard, P.A. Bjorn, B. Finstad, R. Knudsen, J. R. Dempson, J.C. Holst, N.A. Hvidstenard, M. Holm. 2004. Geographical differences in marine feeding of Atlantic salmon postsmolts in Norwegian fjords. *J. Fish. Bio.* 64(6): 1655-1679
- Rimmer, D.M., U. Paim, and R.L. Saunders. 1984. Changes in the selection of microhabitat by juvenile Atlantic salmon (*Salmo salar*) at the summer-autumn transition in a small river. *Can. J. Fish. Aquat. Sci.* 41(3): 469-475
- Ritter, J.A. 1989. Marine migration and natural mortality of North American Atlantic salmon (*Salmo salar* L.). *Can. MS Rep. Fish. Aquat. Sci. No. 2041.* 136pp
- Robinson, K.W., S.M. Flanagan, J.D. Ayotte, K.W. Camp, A. Chalmers, J.F. Coles, and T.F. Cuffney. 2004. *Water Quality in the New England Coastal Basins, Maine, New Hampshire, Massachusetts, and Rhode Island, 1999-2001.* USGS Circular 1226
- Rosseland B. O. and O. K. Skogheim. 1984. A comparative study on salmonid fish species in acid aluminum-rich water II. Physiological stress and mortality of one- and two-year-old fish. *Inst. Freshwater Res. Drottningholm Rep.* 61: 186-194
- Rosseland B. O., T. D. Eldhuset and M. Staurnes. 1990. Environmental effects of aluminum. *Environ. Geochem. Health.* 12: 17-27
- Ruggles, C.P. 1980. A review of the downstream migration of Atlantic salmon. *Canadian Technical Report of Fisheries and Aquatic Sciences No. 952.* Freshwater and

- Anadromous Division Research Branch, Department of Fisheries and Oceans.
Halifax, NS. 39pp
- Saunders, J.W. 1960. The effect of impoundments on the population and movements of Atlantic salmon in Ellerslie Brook, Prince Edward Island. Jour. Fish. Res. Bd. Canada, 17(4): 453-473.
- Saunders R.L., E.B. Henderson, B.D. Glebe and E.J. Loundenslager. 1983a. Evidence of a major environmental determination of the grilse: larger salmon ratio in Atlantic salmon (*Salmo salar*). Aquaculture. 33: 107-118
- Saunders, R., M. A. Hachey, C. W. Fay. 2006. Maine diadromous fish community: past, present, and implications for Atlantic salmon recovery. Fisheries. 31(11): 537-547
- Saunders, R.L., E.B. Henserson, P.R. Harmon, C.E. Johnston and J.G. Eales. 1983b. Effects of low environmental pH on smolting Atlantic salmon (*Salmo salar*). Can. J. Fish. Aquat. Sci. 40: 1203-1211
- Schaffer, W.M. and P.F. Elson. 1975. The adaptive significance of variations in life history among local populations of Atlantic salmon in North America. Ecology 56: 577-590
- Schindler, D.W., P.J. Curtis, S.E. Bayley, K.G. Beaty, B.R. Parker, and M.P. Stainton. 1997. Climate and acidification induced changes in the dissolved organic carbon budgets of boreal lakes. Biogeochem. 36: 9-28
- Schofield, C.L. 1981. Aquatic effects of acid rain. International Atlantic Salmon Foundation Special Publication No. 10: 17-20
- Scholz, N.L., N.K. Truelove, B.L. French, B.A. Berejikian, T.P. Quinn, E. Casillas, and T.K. Collier. 2000. Diazinon disrupts antipredator and homing behaviors in Chinook salmon (*Oncorhynchus tshawytscha*). Canadian Journal of Fisheries and Aquatic Sciences 57(9): 1911-1918
- Schuum, S.A. 1977. The fluvial system. John Wiley and Sons, New York, NY.
- Scott, W.B. and E.J. Crossman. 1973. Freshwater Fishes of Canada. Bulletin 184. Fisheries Research Board of Canada. Ottawa, Ca.
- Scott, W.B. and M.G. Scott. 1988. Atlantic Fishes of Canada. Canadian Bulletin of Fisheries and Aquatic Sciences No. 219. 731pp.
- Secombes, C.J. 1991. Current and future developments in salmonid disease control *in* Interactions between fisheries and the environment. Proceedings from the Institute of Fisheries Management 22nd Annual Study Course. Pages 81-87
- Sharpe, F.P. 1962. Some observations of the feeding habits of brown trout. The Progressive Fish Culturist 24(2): 60-64

- Shelton, R.G.J., J.C. Holst, W.R. Turrell, J.C. MacLean, I.S. McLaren. 1997. Young Salmon at Sea. *In: Managing Wild Atlantic Salmon: New Challenges – New Techniques*. Whoriskey, F.G and K.E. Whelan. [eds.]. Proceedings of the Fifth Int. Atlantic Salmon Symposium, Galway, Ireland.
- Shepard, S.L. 1995. Atlantic Salmon Spawning Migrations in the Penobscot River, Maine: Fishways, Flows and High Temperatures. M.S. Thesis. University of Maine. Orono, ME. 112pp.
- Sidle, R.C., A.J. Pearce, and C.L. O’Laughlin. 1985. Hillslope stability and land use. Water Resources Monograph Series 11
- Sigler, J. W., T. C. Bjornn, and F. H. Everest. 1984. Effects of chronic turbidity on density and growth of steelheads and Coho salmon. *Transactions of the American Fisheries Society*. 113: 142-150
- Simenstad, C. A., J. R. Cordell, and L. A. Weitkamp. 1991. Effects of substrate modification on littoral flat meiofauna: Assemblage structure changes associated with adding gravel. FRI-UW- 9124. Wetland Ecosystem Team, Fisheries Research Institute, School of Fisheries, University of Washington, Seattle, Washington. 91pp
- Smith, I.P., G.W. Smith. 1997. Tidal and diel timing of river entry by adult Atlantic salmon returning to the Aberdeenshire Dee, Scotland. *J. Fish. Biol.* 50(3): 463-474
- Smith, T.R. and T.A. Haines. 1995. Mortality, Growth, Swimming Activity and Gill Morphology of Brook trout (*Salvelinus fontinalis*) and Atlantic salmon (*Salmo salar*) Exposed to Low pH with and without Aluminum. *Environmental Pollution* 90(1): 33-40
- Solomon, D.J. 1978. Migration of smolts of Atlantic salmon (*Salmo salar* L.) and sea trout (*Salmo trutta* L.) in a chalkstream. *Environmental Biology of Fishes*. 3(2): 223-229
- Somero, G.N. and G.E. Hofmann. 1997. Global warming: implication for freshwater and marine fish. *Soc. For Exp. Bio. Seminar Series*. No. 61 p. 1-24
- Spence, B.. C., G. A. Lomnicky, R. M. Hughes, and R. P. Novitzki. 1996. An ecosystem approach to salmonid conservation. TR-4501-96-6057. ManTech Environmental Research Services Corp., Corvallis OR. (Available from the National Marine Fisheries Service, Portland, Oregon.)
- Sprague, J., P. Elson, and R. Saunders. 1965. Sublethal copper-zinc pollution in a salmon river – A field and laboratory study. *International Journal of Air and Water Pollution*. 9: 531-543

- Stasko, A. B., R. M. Horrall, A. D. Hasler, and D. Stasko. 1973. Coastal movements of mature Fraser River pink salmon (*Oncorhynchus gorbuscha*) as revealed by ultrasonic tracking. *Journal of the Fisheries Research Board of Canada* 30: 1309-1316
- Stasko, A.B. 1975. Progress of migrating Atlantic salmon (*Salmo salar*) along and estuary, observed by ultrasonic tracking. *J. Fish. Biol.* 7: 329-338
- Staurnes M., L. P. Hansen, K. Fugelli, and O. Haraldstad. 1996. Short-term exposure to acid water impairs osmoregulation, seawater tolerance, and subsequent marine survival of smolts of Atlantic salmon (*Salmo salar* L.). *Can. J. Fish. Aquat. Sci.* 53: 1695-1704
- Staurnes, M., F. Kroglund, and B.O. Rosseland. 1995. Water quality requirements of Atlantic salmon (*Salmo salar*) in water undergoing acidification or liming in Norway. *Water Air and Soil Pollution* 85: 347-352
- Staurnes, M., P. Blix, and O.B. Reite. 1993. Effects of acid water and aluminum on parr smolt transformation and seawater tolerance in Atlantic salmon, *Salmo salar*. *Canadian Journal of Fisheries and Aquatic Sciences* 50: 1816-1827
- Stefansson, S.O., B.TH. Bjornsson, K. Sundell, G. Nyhammer, S.D. McCormick. 2003. Physiological characteristics of wild Atlantic salmon post-smolts during estuarine and coastal migrations. *J. Fish. Bio.* 63(4): 942-955
- Stevenson, C.H. 1898. The Shad Fisheries of the Atlantic Coast of the United States. Report of the Commissioner for the year ending June 30, 1898 Part XXIV. U.S. Commission of Fish and Fisheries. 101-269
- Stockner J. G. and K. I. Ashley. 2003. Salmon nutrients: closing the circle. *American Fisheries Society Symposium* 34: 3-15
- Stockner, J. G., 1987. Lake fertilization: the enrichment cycle and lake sockeye salmon (*Oncorhynchus nerka*) production. Pages 198-215 *In*: H.D. Smith, L. Margolis, and C. C. Wood, editors. Sockeye salmon (*Oncorhynchus nerka*): population biology and future management. *Canadian Fisheries and Aquatic Sciences, Special Publication Number 96*
- Stradmeyer, L. and J.E. Thorpe. 1987. Feeding behaviour of wild Atlantic salmon, *Salmo salar* L. parr in mid- to late summer in a Scottish river. *Aquaculture and Fisheries Management* 18: 33-49
- Sturlaugsson, J. 1994. Food of ranched Atlantic salmon (*Salmo salar* L.) postsmolts in coastal waters, W. Iceland. *Nordic J. of Fresh. Research.* 69: 43-57
- Sturlaugsson, J. 2000. The food and feeding of Atlantic salmon (*Salmo salar* L.) during feeding and spawning migrations in Icelandic coastal waters. 193-210 *In*: The

- Ocean Life of Atlantic Salmon. Environmental Factors Influencing Survival (ed. D. Mills). Fishing News Books, Oxford, pp. 228
- Sullivan, K., T. E. Lisle, C. A. Dolloff, G. E. Grant, and L. M. Reid. 1987. Stream channels: the link between forests and fishes. Pages 39-97 *In: Streamside Management: Forestry and Fishery Interactions* (eds. Salo, E.O. and T.W. Cundy). Proceedings of a Symposium held at University of Washington, 12-14 February 1986. Contribution no. 57, Institute of Forest Resources, Seattle, Washington
- Swansburg, E., G. Chaput, D. Moore, D. Caissie, and N. El-Jabi. 2002. Size variability of juvenile Atlantic salmon: links to environmental conditions. *Journal of Fish Biology* 61: 661-683
- Symons, P. and M. Heland. 1978. Stream habitats and behavioral interactions of underyearling and yearling Atlantic salmon (*Salmo salar*). *J. Fish. Res. Bd. Can.* 35: 175-183
- Tautz, A.F., and C. Groot. 1975. Spawning behavior of chum salmon (*Oncorhynchus keta*) and rainbow trout (*Salmo gairdneri*). *J. Fish. Res. Bd. Can.* 32: 633-642
- Taylor, J.N., W.R. Courtenay Jr., and J.A. McCann. 1984. Known impacts of exotic fishes in the continental United States. *In: Distribution, biology, and management of exotic fishes.* W.R. Courtenay Jr. and J.R. Stauffer Jr. eds. The Johns Hopkins University Press, Baltimore, MD. Pages 322-373
- Templeman, W. 1968. Distribution and characteristics of Atlantic salmon over oceanic depth and on the bank and shelf slope areas off Newfoundland. March-May 1966. *Res. Bull. Int. Comm. NW Atlantic Fish.* 5: 62-85.
- Thom, R. M., and D.K. Shreffler. 1996. Eelgrass meadows near ferry terminals in Puget Sound. Characterization of assemblages and mitigation impacts. Battelle Pacific Northwest Laboratories, Sequim, WA
- Thompson, E. and W. Cooke. 1991. Enhancement of hardshell clam habitat by beach graveling. *In: Proceedings of Puget Sound Research 1991.* pp521-527. Puget Sound Water Quality Authority, Seattle, Washington
- Thorpe, J.E. 1994. Salmonid Fishes and the Estuarine Environment. *Estuaries.* 17(1): 76-93
- Thorpe, J.E. and Morgan, R.I.G., 1978. Periodicity in Atlantic salmon, *Salmo salar* L., smolt migration. *J. Fish Biol.* 12: 541-548
- Thurman, E.M. 1985. *Organic Geochemistry of Natural Waters.* Martinus Nijhoff, Dordrecht, 469 p.

- Trombulak, S.C. and C.A. Frissell. 2000. Review of ecological effects of roads on terrestrial and aquatic communities. *Conservation Biology* 14(1): 18-30
- United States Department of Agriculture (USDA) . 1997 Census of Agriculture. Maine State and County Data. U.S. Department of Agriculture AC97-A-19. Issued March 1999.
- United States Department of Agriculture (USDA). 2002 Census of Agriculture. Maine State and County Data. U.S. Department of Agriculture AC-02-A-19. Issued June 2004.
- USACE (United States Army Corps of Engineers). 1984. Shore protection manual. prepared for Department of the Army, Vicksburg, Miss. : Dept. of the Army, Waterways Experiment Station, Corps of Engineers, Coastal Engineering Research Center ; Washington, D.C.
- USACE (United States Army Corps of Engineers). 2007. National inventory of Dams. <http://crunch.tec.army.mil/nidpublic/webpages/nid.cfm>
- USASAC (United States Atlantic Salmon Assessment Committee). 2004. Annual Report of the U.S. Atlantic Salmon Assessment Committee Report No. 16 – 2003 Activities. Annual Report 2004/16. Woods Hole, MA – February 23-26, 2004. 74pp. and appendices
- USASAC (United States Atlantic Salmon Assessment Committee). 2005. Annual Report of the U.S. Atlantic Salmon Assessment Committee Report No. 17 – 2004 Activities. Annual Report 2005/17. Woods Hole, MA – February 28-March 3, 2005. 110pp. and appendices
- USEPA (United States Environmental Protection Agency). 2000. National Water Quality Inventory – 2000 Report. Assessment and Watershed Protection Division. 1200 Pennsylvania Ave. N.W. Washington D.C.
- USEPA (United States Environmental Protection Agency). 2003. National Management Measures for the Control of Nonpoint Pollution from Agriculture. Office of Water (4503T), 1200 Pennsylvania Avenue, NW, Washington, D.C. 20460. EPA-841-B-03-004
- USFWS (United States Fish and Wildlife Service) – Gulf of Maine Coastal Program (GOMP). 2004. ASHAB3. Maine Office of Geographic Information Systems (MEGIS). Augusta, ME
- USFWS (United States Fish and Wildlife Service). 1989. Final environmental impact statement 1989-2021: restoration of Atlantic salmon in New England. Department of the Interior, U.S. Fish and Wildlife Service. Newton Corner, MA. 88pp. and appendices.

- USGS (United States Geological Survey. 2006. Mineral Industry Surveys. U.S. Peat Producers in 2005. **Internet:** <http://minerals.usgs.gov/minerals>
- Van Brummelen, T.C., B. van Hattum, T. Crommentuijn, and D.F. Kalf. 1998
Bioavailability and Ecotoxicity of PAH. In: Neilson, A.H. (ed.). PAH and Related Compounds – Biology. (Vol. 3-J, The Handbook of Environmental Chemistry). Springer – Verlag, Berlin Heidenberg. Pp. 203-263
- Van Der Kraak, G. and N.W. Pankhurst. 1997. Temperature effects on the reproductive performance of fish. C.M. Wood and D.G. McDonald, eds. Cambridge University Press, Cambridge, United Kingdom. Pages 159-176
- Vannote, R. L., G. W. Minshall, K. W. Cummins, J. R. Sedell, and C. E. Cushing. 1980. The river continuum concept. *Canadian Journal of Fisheries and Aquatic Sciences*. 37:130-137
- Vincent, H.R., Brown, A.V., Covich, A., Grutz, M., Li, H., Minshall, G., Reice, S., Sheldon, A., Wallace, B., Wissmar, R.. 1988. The role of disturbance in stream ecology. *J. N. Am. Benthol. Soc.* 7(4):433-455
- Vines, C.A., T. Robbins, F.J. Griffin, and G.N. Cherr. 2000. The effects of diffusible creosote derived compounds on development in Pacific Herring (*Clupea pallasii*). *Aquatic Toxicology* 51(2): 225-239
- W. Kelley. 1961. The influences of inorganic sediment on the aquatic life of streams. *California Fish and Game* 47:189-228
- Waters, T. W. 1995. Sediment in streams: Sources, biological effects, and control. *American Fisheries Society Monograph* 7.
- Watts, J. G. 1987. Physical and biological impacts of bulkheads on North Carolina's estuarine shoreline. Division of Coastal Management, North Carolina Department of Environment, Health, and Natural Resources
- Weaver, C. 1963. Influences of water velocity upon orientation and performance of adult migrating salmonids. *Fish. Bull.* 63: 97-121. U.S. Fish Wildl. Serv., Washington, D.C.
- Webb, J.H., D.W. Hay, P.D. Cunningham, and A.F. Youngson. 1991. The spawning behavior of escaped farmed and wild adult Atlantic salmon in a northern Scottish river. *Aquaculture* 98(1/3):97–110
- Weitkamp, D. E. 1982. Juvenile chum and chinook salmon behavior at Terminal 91, Seattle, Washington. Report by Parametrix, Inc. to Port of Seattle, Seattle, Washington. 21p.

- Whalen, K. G., D. L. Parrish, and M. E. Mather. 1999a. Effect of ice formation on selection habitats and winter distribution of post-young-of-the-year Atlantic salmon parr. *Canadian Journal of Fisheries and Aquatic Sciences* 56(1): 87-96
- Whalen, K. G., D. L. Parrish, and S. McCormick. 1999b. Migration timing of Atlantic salmon smolts relative to environmental and physiological factors. *Trans. of the Amer. Fish. Soc.* 128: 289-301
- White R. J., J. R. Karr, and W. Nehlsen. 1995. Better roles for fish stocking in aquatic resource management. Pages 527–547 in H. L. Schramm, Jr., and R. G. Piper, editors. *Uses and effects of cultured fishes in aquatic ecosystems*. American Fisheries Society, Symposium 15, Bethesda, Maryland.
- White, H.C. 1942. Atlantic salmon redds and artificial spawning beds. *J. Fish. Res. Bd. Can.* 6: 37-44
- Whoriskey, F. G., P. Brooking, G. Doucette, S. Tinker and J.W. Carr. 2006. Movements and survival of sonically tagged farmed Atlantic salmon released in Cobscook Bay, Maine USA. *ICES J. Marine Sci.* 63(7): 1263-1268
- Wickett, W.P. 1954. The oxygen supply to salmon eggs in spawning beds. *J. Fish. Res. Board Can.* 6: 933-953
- Wildish, D. J., and J. Power. 1985. Avoidance of suspended sediments by smelt as determined by a new "single fish" behavioral bioassay. *Bull. Environ. Contam. Toxic.* no. 34: 770-774
- Williams, B. and C. Betcher. 1996. *Impact of Mooring Buoy Installations on Eelgrass and Macroalgae*, Wash. Dept. Fish and Wildlife
- Williams, G. D. and R.M. Thom. 2001. *Marine estuarine shoreline modification issues*. Battelle Marine Sciences Laboratory, Pacific Northwest National Laboratory. White Paper: 121 pp.
- Wipfli, M.S., Hudson, J., and Caouette, J. 1998. Influence of salmon carcasses on stream productivity: response of biofilm and benthic macroinvertebrates in southeastern Alaska, U.S.A. *Can. J. Fish. Aquat. Sci.* 55: 1503-1511
- Worrall, F., Burt, T & Shedden, R. 2003. Long term records of riverine dissolved organic matter. *Biogeochemistry* 64: 165-178
- Wright, R., T. Dale, E. Gjessing, G. Hendrey, Al Hericksen, M. Johannessen, and I. Muniz. 1976. *Impacts of acid precipitation on freshwater ecosystems in Norway*. United States Forest Service General Technical Report NE-23: 459-476