Invasive Species Report

Atlantic Salmon (*Salmo salar*)

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Figure 1. Male Atlantic salmon (top), Female Atlantic salmon (bottom)

**Diagnostic Information**

Order: Salmoniformes

Family: Salmonidae

Genus: Salmo

Species: Salar
Common name: Atlantic Salmon

![Atlantic Salmon illustration]

Figure 2. Atlantic salmon have a forked caudal fin which is more apparent in standard lengths under 20 cm.

**Identification Key**

The Atlantic salmon (*Salmo salar*) has a slender silvery body, small head, blunt nose, small eyes, large scales, slightly forked caudal fins, adipose fin, a mouth that gaps back below it’s eye, and has a row of conical stout teeth. They grow to be 2-3 feet long and can weight up to 10lbs. They have a forked caudal fin (Fig. 2). They have small x shaped spot without halos present.

**Life-history and basic ecology**
Atlantic salmon are anadromous. They have the ability to move between freshwater and saltwater. They begin life upstream in fresh water and then move downstream and out into the ocean where they increase their body fat before returning back upstream to spawn. This means that physiologically their bodies must change to be able to accommodate first fresh water then salt water and then back again to fresh water. The ocean migration brings large growth, but uses much energy because of the physiological changes required to go between freshwater and saltwater and to change to a radically different food source, that is fish instead of insects. Furthermore, “as it migrates a smolt alters its behavior from that of a freshwater, territorial, benthic individual to a pelagic, possibly shoaling fish at sea” (Oystein et al, 2011). There physiology must change drastically as they change “from a freshwater organism that had formerly struggled to maintain its internal salt content, to an ocean dweller inundated with dangerous quantities of salt that must excreted” (Oystein et al, 2011). Atlantic salmon have complex life cycles. Not all the salmon migrate. Some populations completed their lifecycle in freshwater or only migrate to estuaries before returning to spawn. Most are able to return to their original spawning area. Both age and size at maturity vary depending on environmental factors. This variation occurs in and among different populations, as does how far they migrate. These variations in lifecycle are at least partly due to varying environmental conditions. Any biotic or abiotic factor influencing health and body size will affect when they become smelt and mature adults. Atlantic salmon with very different life history and migrations may exist in the same area. Atlantic salmon deposit orange pea-sized eggs in gravel riverbeds and ponds during the late autumn months. The eggs hatch in early spring and give rise to alevins. The alevins remain in the gravel redd, feeding from their yolk sac for 4-6 weeks; after which, they emerge to surface to take in air that will fill their swim bladders. At this point they are called fry. The fry disperse and feed on small invertebrates, fish eggs and plankton. During this time they develop red spots on their sides by which vertical striations appear, camouflaging the fry to their environment. The salmon stay fry for 2 to 4 seasons or until they are 6 inches long. Once their appearance is fully developed the fry become parr. The parr are large enough to feed on worms, shellfish, and other parr. Parr can be territorial and will starkly defend their area from other parr. This life stage can last between 2-6 years after which the fish migrate to the brackish environments and become smolts. Smoltification is a process by which the parr physiology changes to adapt to salt water conditions. Smolts are often found in brackish water such as estuaries and bays until the spring in which they have completed these physiological changes at which point they migrate to the ocean and are considered adult. They the adult stays only one year at sea before returning to their natal spawning grounds they salmon is known a grilse. If the adult stays longer than one year it is known as a multi-sea winter salmon. The salmon eat abundantly during this time in efforts to store a large amount of fat for the river ascent back to their natal spawning grounds to mate. During the ascent back to their spawning grounds the salmon do not eat and instead rely on these fat stores for energy. After mating the female and male then rest until they are ready to begin the migration back to the ocean; this is a distinct difference between the Salmon and the Onchorynchus genus which includes species such as Chinook, Sockeye, Chum, Coho and Pink salmon, which generally die after spawning due to exhaustion.

Feeding habits
Atlantic salmon in streams feed mainly upon stoneflies, blackflies, larvae, aquatic insects, as well as chironomids, mayflies and caddisfly nymphs. “At sea, Atlantic salmon eat a variety of marine organisms, including crustaceans such as euphausiids, amphipods and decapods, and such fishes as sand lance, smelt, herring, capelin, small mackerel and small cod” (Scott and Crossman, 1973). Atlantic salmon utilizes different food sources, depending on their development stage. Newborn Atlantic salmon (Alevins) consume egg sac yolk for nourishment until they grow large enough (fry and parr) to feed on insect larva and nymphs such as “… mayflies, caddisflies, blackflies and stoneflies” (Waknitz, et al 2003). As juveniles, they require a high protein diet of 45-50 percent, and a lipid content of 23-27 percent to meet nutritional requirements during this period of rapid growing. During the winter the juveniles experience significant weight and body composition loss due to decreased food supplies and their lipid consumption can drop to as low as 4-12 percent. During the late spring and early summer juvenile Atlantic salmon often shift prey selection towards terrestrial insects, as they become more abundance. One important factor in determining diet preference is the availability of aquatic invertebrates by which Atlantic salmon may feed upon. The amount of invertebrates available is related to various ecological factors such as nutrient enrichment. When the ecosystem produces more nutrients, the corresponding increase algae, attracts insects. The juvenile diet greatly overlaps that of the adult Atlantic salmon between the first and second year spawners (the griselee and the 2sw). Comparisons of their stomach content reveal similar diet compositions. Frequent prey groups include various types of crustaceans such as hyperiid amphipods, euphausiids, and shrimp; as well as various types of fish such as herring, alewives, smelts, capelin, cod, sand lance, and small mackerel. In comparison to the 1\textsuperscript{st} and 2\textsuperscript{nd}; the 1\textsuperscript{st} and 3\textsuperscript{rd} year salmon show greater differences as the degree of piscovory is greater in larger salmon (3\textsuperscript{rd} year). Older salmon consume a substantially great amount of fish when compared to younger salmon. This is likely because they are simply larger which increases the amount of prey they can select from.

Reproductive strategies

Atlantic salmon (Salmo salar) spawn in the late fall (October, November). A mature female selects a spawning location, usually in the far side of a pond or in a stream. When a spawning site has been determined; the female waits for a fit male. Once courtship is accepted, the female Atlantic salmon turns her body sideways while fluctuating her caudal fin and peduncle to create water flow that will make a hollow in the stream gravel called a redd. Redds are between 10-30cm deep. The female then lays her in eggs in the redd, while the male simultaneously moves alongside her releasing his milt (sperm). Fertilization then occurs as both gametes intermingle. The male guards against intruding males while she continues to create redds in the gravel while depositing her eggs for fertilization after each redd is complete. This process continues until all of her eggs are deposited (average 700-800 eggs per pound of body weight) which is accomplished with between 6-9 redds. This courtship ritual can take up to a week. At the end of this time period both the male and female are exhausted. Reproduction in Atlantic salmon involves the use of "substantial amounts of resources which are obtained throughout the life of the salmon” (Jacobsen, 2000). This investment of resources is used for the production of gametes, migration, courtship, and competition for nesting sites and mates. About 60% of the energy obtained from the salmon goes to reproduction. Females used it for egg production and males use it in competition for females, including the secondary sexual characteristics of hooked snouts and gaudy breeding coloration. Both age and size at maturity are determined by environmental factors. Maturity is delayed when the growth rate is slowed
because of unfavorable environmental conditions. This delay occurs early if the growth rate levels off quick. Males show greater diversity of size than females. Female size is limited because of the need to produce eggs. While males are free to use different techniques to access mating opportunities. While some males go for large size to ward off competing males, others remain small (juvenile) and use stealth behaviors to fertilize eggs. These smaller males may be using a default developmental pathway because they failed to reach the threshold size, which activates a gene that suppresses maturation. Those fish that undergo migration generally have a higher reproductive investment than those that do not. Larger females have larger eggs. The probability of repeat breeding decreases with increased fish size. Juveniles near nesting sites are attacked by both male and female anadromous salmon. Females decided when and where to lay eggs thus determining the environment in which the eggs will hatch. Breeding time relates to water temperature. Early breeders get the best nest sites, but risk destruction of these nest sites. Females prefer building nests on the upside of gravel bars where the current is accelerating and the water depth decreasing. Her breeding success depends on fecundity, nesting success, and fertilization. It increases with her body size. Anatropous males form hierarchies around nesting females. The dominant male performs most of the courting behavior, which includes quivering, nudging and crossover.

Environmental optima and Tolerances

Atlantic salmon have similar environmental conditions as other salmonid species to maintain optimal health. Ideal water temperature will vary depending on the stage of the salmon; however all stages require cool temperatures for the fish to thrive. During the spawning process optimal fertilization occurs at water temperatures of 4 – 10 degrees Celsius. If the temperature increases above 12 degrees Celsius the likelihood of egg mortality significantly increases. Despite these ideal temperature ranges, eggs can persistent at temperatures as low as .5 degree Celsius. Once the salmon are alevins, they seek a higher water temperature. “About 250 degree days after hatching the alevins select a temperature of 14 degrees – 19 degrees Celsius, with an optimum growth temperature of 16.6 degrees Celsius” (Peterson and Metcalfe, 1979). However, alevins can persist in water temperatures as high as 27 degrees Celsius, but only for a brief time before seeking cooler waters. The water temperature becomes lethal to juvenile Atlantic salmon (S. salar) when it reaches 32 degrees Celsius or above. Adult Atlantic salmon require water temperatures between 2-28 degrees Celsius. Temperatures above 20 degrees Celsius increase the risk of disease, while temperatures above 28 degrees Celsius are found to be fatal.

The percentage of dissolved oxygen is another important environmental factor for optimum growth and health. Atlantic salmon require a minimum dissolved oxygen saturation level of 6 mg/l. Dissolved oxygen below this threshold level result in depressed respiration. Specifically, “the respiration of adult Atlantic salmon is depressed at oxygen concentrations below 4.5-5 mg/l (Kazakov and Khalyapina, 1981). At oxygen concentration below 1.7 mg/l death occurs for adult salmon. Age, sex, and weight, are major factors influencing oxygen requirements. Atlantic salmon younger than parr require a minimum oxygen concentration of 1.1 mg/l. Older adults also use less oxygen as the rate of oxygen consumption decreases with age or body weight.

Atlantic salmon require a pH greater than 6 to avoid problems associated with seawater tolerance. A pH < 5 results in ion loss and a decrease in blood volume as water shifts from extracellular to intracellular fluid. This condition also varies depending on the stage of
development with sensitivity at it’s highest in the following order: “...fry>smolt>small parr>large parr>alevin>egg....” (farmer, 2004).

**Biotic associations**

Atlantic salmon (Salmo salar) vulnerably to parasites, fungal, and viral pathogens are contextual on environmental conditions and life stage development. Adult Atlantic salmon in marine environments often risk infections from pathogens separate to their freshwater stages, but even adults returning to freshwater natal spawning site will face risk from pathogens not encounter during their earlier life stages. Many pathogens affecting freshwater Atlantic salmon populations are not well understood in the Pacific Northwest. “Parasites and diseases affecting Atlantic salmon in fresh water, and the potential transfers of pathogens from farmed salmon to native species, have not received much research attention in the Pacific Northwest” (Bisson, 2006). However, one organism in particular (affecting juveniles to adults) has received significant attention from the British Columbia scientific community, the Sea louse (Lepeophtheirus salmonis). This copepod ectoparasite enters through protective mucous membranes and attacks the salmon directly by reducing osmoregulation and growth, causing skin lesions, and damaging the caudal and dorsal fins. Sea louse also affect Atlantic salmon (S. salar) passively by transmitting the Infectious Salmon Anemia (ISA) virus, which is a member of the Orthomyxoviridae family. Fish have DNA in their red blood cells, which can get infected with the virus, causing cell death and ultimately circulatory system shut down. As with many other infectious salmon diseases, aquaculture farming has been responsible for the transfer of ISA to wild Atlantic salmon as escapes can transfer the virus to wild populations “...no reports of diseases or parasites from salmon farms invading freshwater ecosystems within the Pacific Northwest. It’s a different story within marine waters. Close quarters within aquaculture pens frequently results in eruptions of sea lice” (Bisson 2008). Other enzootic parasites of concern to Atlantic salmon populations in the Pacific Northwest are Kudoa thyrsites, Furunculosis (Aeromonas salmonicida), and the Infectious Hematopoietic Necrosis Virus (IHNV). Kudoa thyrsites breaks down muscle fibers in the sarcolemma leading to a gelatinous muscle mass. Furunculosis is a bacterial infection that affects Atlantic salmon in both fresh and saltwater stages. The infection causes boils to develop on their sides. Like ISA, Furunculosis was spread to the wild Atlantic salmon population through aquaculture practices. “Escaped farmed salmon may also be a significant source of furunculosis infections in natural salmon populations (Johnsen and Jensen 1994).” IHNV is thought to be a particularity infectious to Atlantic salmon. “A possible explanation for the greater susceptibility of Atlantic salmon to IHN is that this fish is exotic to the Pacific Northwest and, therefore, probably has less innate resistance to the virus than indigenous salmonid species.” (Traxler et al, 1993). The disease causes building eyes, hemorrhaging of internal organs and pancreas necrosis.

3. **Current geographic distribution**

*Distribution in the PNW and the United States*

Native Atlantic salmon (S. salar) occupied the North Atlantic ocean from Maine in the United States to the Barents Sea north of Russia. Due to commercial and recreational fishing they have been raised in aquaculture in cold areas around the world including South American and Pacific Northwest. They also inhabit the Pacific Northwest from Alaska down to Oregon and especially abundance on Vancouver Island.
4. History of Invasiveness

The history of Atlantic salmon (S. salar) released in the Pacific northwest begins over a century ago. From 1903 to 1935, it has been estimated that “over 8.6 million Atlantic salmon of various life stages (predominately advanced fry) were intentionally introduced to more than 60 individual BC lakes and streams” (Ginetz, 2002). The intentional introductions of Atlantic salmon into freshwater systems continued in Washington state beginning in 1951 with a release of 3,821 salmon in Chamber’s creek, and in 1953 a release of 8000 in Alexander creek. Until 1991, similar numbers and (Between 140 – 15,811) of Atlantic salmon were intentionally released into various lakes in Washington with little success of establishment. In contrast to freshwater releases; saltwater releases have been largely unintentional with the main pathway of invasion being aquaculture facilities and the vector being escapes from pens. These escapes into saltwater regions increased greatly in the early 1980’s when Atlantic salmon (Salmo salar) was brought over to the PNW to be harvested in aquaculture facilities. This increase of escapes was primarily due to the vast amount of farms exclusively raising Atlantic salmon which turn increased the amount of total yearly escapes. These escapes are still problematic today.

Invasion process

Pathways

The invasion process of Atlantic salmon in the Pacific Northwest is facilitated through British Columbia’s aquaculture industry (it is the pathway by which they are unintentionally released). Fish pens may break in the presence of storms or damage from animals such as Sea lions that are attracted to the pen. The cost of fixing damaged aquaculture facilities often outweighs the loss of profit from escaped fish. Because of this, aquaculture managers often overlook the ecological consequences of escapes, facilitating the release of thousands of Atlantic salmon into pacific northwest waterways. There are more than 10 times as many aquaculture facilities in British Columbia as there are in Washington state with counts exceeding 130. Most of these facilities are located along Vancouver Island. See Figure sdfdfd. “based on the reported escapes alone, between 1996 and 1999, more than 2 million fish escaped from Washington salmon farms.” And “In British Columbia, records indicate that between 1991 and 2002, a total of 452,049 Atlantic salmon escaped from farms.” (Ginetz, 2002). Although escapes only average.5-1% of farm pen populations, it still provides a consistent propagule number, which greatly increases the likelihood of Atlantic salmon establishment.

Factors influencing Establishment and spread

The major factors human introductions into the wild although that is less common now it has a long history within freshwater bodies in Washington state. Others factoring include how much competition there is for resources among top competitor such as Steelhead trout and the Brown Trout (a close relative of the S. salar) Atlantic salmon in the rest of the world are actually in retreat and therefore might not be that be of a concern. Although this salmon
species is found around Vancouver it has not established in the wild “Farm-cultured Atlantic salmon sites are established in the Pacific Northwest, and cage-escaped adult salmon are commonly found in rivers at Vancouver Island. Two-year classes of Atlantic salmon parr from natural reproduction of escaped cultured fish have also been found in a river on Vancouver Island, British Columbia.” (Behnke, 2002). Other vectors of introduction include intentional lake stocking of Atlantic salmon for sport fishing purposes. For example, in “in 1991, 6083 were introduced into Pass Lake, WA” (Behnke, 2002). Despite various attempts to introduce Atlantic salmon in the Pacific Northwest, the invasive species has only naturally reproduced on a few rivers located on Vancouver Island as 2000. “The recovery of two age-classes of feral juvenile Atlantic salmon in the Tsitika river (1998), and the single age-classes in both the Amor de Cosmos Creek (1999, 2000) and the Adam River (1999), confirmed that escaped Atlantic salmon are capable of successfully producing offspring in the wild. This is not surprising given the historical experience in BC.

Potential ecological and/or economic impacts

There is no evidence that a self-sustaining population has developed and that Pacific salmon and steelhead are being displaced or taken over” (WDFW 2002). This may indicate that propagule number is not currently sufficient enough to facilitate establishment over the biotic resistance of the recipient community in the PNW and/or that the local ecosystem provide high biodiversity and biotic resistance to non-natives from entering the community. Over time this situation may change if interspecific competitors such as the Chinook or Coho salmon decrease in population size. However, currently, “reasons for the successful introduction by some salmonids, and failures of others including Atlantic salmon, are not clear. All of the evidence suggests that colonization is dependent upon one or more factors including the ability to compete for food, space and cover, and water tolerance to a wider range of environmental conditions” (Ginetz, 2002). The majors concerns of are that the Atlantic salmon will naturalize in the PNW and reproduce with the native population of Brown Trout and Pacific salmon which could alter the genetic diversity of native stocks. A decrease in genetic diversity with in the salmon population would also bring a reduction in nutrients as less salmon carcasses would occur in nature. Despite this, little is known about the ecological impacts from Atlantic salmon in the PNW. “Less than one percent of British Columbia’s streams possessing potential Atlantic salmon habitat have been surveyed for this species, and the same is surely true for Alaska and Washington. Therefore, the current status of self-reproducing populations of Atlantic salmon in the Pacific Northwest—if any exist—is largely unknown,” (Bisson, 2006).

Current Research and Management Efforts

Various management efforts and control methods have been utilized to prevent economic loss and invasion from Atlantic salmon (salmo salar). One method has been to create stronger aquaculture pens to lessen Atlantic salmon escapes from British Columbia. This is accomplished by using different netting materials, which will not break under stress as easily. This has been made possible by the development of copper alloys, which can serve as replacement materials of facilities which are using outdating materials. “Copper alloys have become important netting materials because they are antimicrobial (i.e., they destroy bacteria, viruses, fungi, algae, and other microbes) and they therefore prevent biofouling (i.e., the undesirable accumulation,
adhesion, and growth of microorganisms, plants, algae, tubeworms, barnacles, mollusks, and other organisms). By inhibiting microbial growth, copper alloy aquaculture cages avoid costly net changes that are necessary with other materials. The resistance of organism growth on copper alloy nets also provides a cleaner and healthier environment for farmed fish to grow and thrive.” (Blackwell, 2011).

Literature Cited

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