Invasive Species of the Pacific Northwest:

Brook Trout (*Salvelinus fontinalis*)

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Diagnostic Information

Taxonomy

Kingdom: Animalia
Phylum: Chordata
Class: Actinopterygii
Order: Salmoniformes
Family: Salmonidae
Genus: *Salvelinus*
Species: *fontinalis*

Common Names

Brook Trout, Speckled Trout, Brook Charr, Aurora Trout, Brookie, Coaster, Sea Trout

Identification Key

Brook trout, like all members of the family salmonidae, have a fusiform (torpedo-like) body shape with paired pectoral and pelvic fins, a singular anal fin just posterior to the vent, and an small adipose fin which is closer to the caudal fin than the dorsal fin (Karas, 1997). Brook trout are also not actually trout, they are in fact a char, which are distinguished from trouts and salmon by having light spots on a dark background, white piping along the outer edge of their pectoral, pelvic, and anal fins, and their scales are much smaller (Karas, 1997).

Brook trout are most easily distinguished from other similar species by the wormlike vermiculations on their back and head, as well as their dorsal, adipose, and caudal fins (Karas, 1997). These vermiculations break up into light spots on their sides (Roberts, 2000). Along with light spots, brook trout have small red spots surrounded by blue halos along their sides (Jansson, 2013).

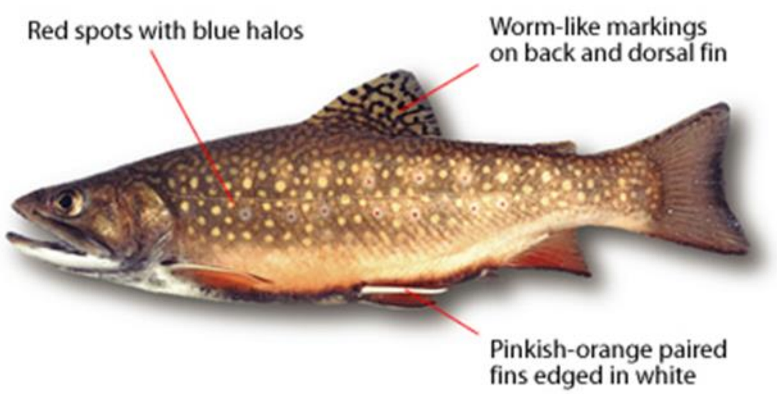

Figure 1. Key identifying markings on brook trout include dorsal vermiculations, white leading edge of pectoral and pelvic fins, and red spots with blue halos along sides. (British Columbia FLNRO)

Typical coloration is a dark greenish brown back which fades down the sides to a light brown and a yellowish color below the lateral line (Karas, 1997). This coloration fades to a pearly white on the abdomen, but this is replaced with a red or orange color with a black swath along the very bottom when spawning (Karas, 1997). Coloration can vary widely depending on environment from a light metallic blue in sea run populations to very dark brown and yellow in populations living in waters tinted by leachates from surrounding conifer forests (Karas, 1997).

The dorsal, adipose, and caudal fins all don the characteristic vermiculations, while the pectoral, pelvic, and anal fins are of a transparent red and sport the typical char white piping along the leading edge (Karas, 1997). This white piping is then followed by a distinct black stripe (Karas, 1997). The ventral portion of the caudal fin may also display the white piping and black stripe in some populations, but is usually not as distinct as on other ventral fins (Karas, 1997). The caudal fins of brook trout are also less forked than many other salmonids, giving it a squared appearance (Naiman et al, 1987).

Like most members of the salmonidae family, brook trout exhibit seasonal dimorphism in preparation for spawning, this is most apparent in males (Karas, 1997). Their body colors will become more vivid, abdominal coloration changes from white to a red or orange with a black swath along the bottom, they may develop a hump under their dorsal fin (though not as pronounced as those seen in Pacific salmon), and will develop a hook, or kype, in the lower jaw (Karas, 1997). The first picture on the cover of this report is a good example of a brook trout in its spawning morph.

Brook trout have a large head, nearly a quarter of its body length, with big eyes and a longer snout than most other chars and trout (Karas, 1997). They also have a much larger mouth with their maxillary jaw extending posteriorly of the eye (Karas, 1997). They have an outer row of teeth visible on the lower jaw, an inner and outer row on the upper jaw, as well as on the tongue and throat but not on the roof of the mouth (Karas, 1997).

Brook trout can also be either residents or anadromous and there are certain morphological differences observed between the two life histories (Morinville and Rasmussen, 2008). Anadromous type brookies tend to be slimmer and more streamlined than their resident cousins; they also usually have shorter pectoral and pelvic fins (Morinville and Rasmussen, 2008). They also take on a more silver coloration when at sea (Karas, 1997).

Figure 2. Sea run brook trout displaying the more silvered appearance than would be seen in a resident trout. (SmugMug – kazyak)

Brook trout size is largely dependent on its habitat and resource availability, with some populations not reaching more than 6 inches at adulthood and others growing larger than 25 inches (Karas, 1997). In ideal conditions, the average adult can reach between 15 and 20 inches and between 2 to 13 pounds (Roberts, 2000). However, most populations are much smaller, typically reaching sizes less than 15 inches and fewer than 4 pounds.

Life History and Basic Ecology

Life cycle and reproductive strategies

Brook trout have two major life histories, being either anadromous or permanent freshwater residents. Some populations of brook trout also display a life history similar to that of anadromy, but instead of migrating out to sea they migrate from their natal streams to large bodies of freshwater such as the Great Lakes (Karas, 1997). Both anadromous and resident populations may spawn in the same waters but are kept separate by slight differences in spawn timing (Karas, 1997).

Both resident and anadromous populations spawn in the late summer and autumn (Roberts, 2000), but specific spawning times are dependent on a number of factors, principally photoperiod with water temperature and precipitation as secondary factors (Karas, 1997). Though certainly not as far as anadromous populations, residents also migrate from their feeding territory to spawning grounds (Karas, 1997).

Brook trout will spawn in small streams, larger rivers, and even on lake bottoms as long as certain conditions are met. The best spawning site will be of pea to walnut sized gravel with a steady supply of well oxygenated water and are free from the dangers of winter ice formation (Karas, 1997). The oxygenated water can be that of the stream or river current or can be from groundwater springs seeping through the gravel into the lake or river (Karas, 1997).

Female spawners will excavate a nest, or redd, by lying on their sides close to the bottom and rapidly undulating their caudal fin, creating a slight vacuum that lifts out sand and gravel (Karas, 1997). She will check her redd for correct depth by lowering herself into it with stiff fins and touching them to the gravel (Karas, 1997).

While the female builds the redd, the male guards the territory from intruding males or pairs looking for a suitable nest site (Karas, 1997). When the redd is complete the male and female will come alongside one another, bodies touching, the female will lower her anal fin deeply into the depression and arch her back, both fish will open their mouths and tremble while releasing their eggs and milt (Karas, 1997). The female then quickly covers the redd in gravel to better protect the eggs (Karas, 1997).

Coordinated release of gametes by both sexes is crucial for proper fertilization because once exposed to water the eggs begin to harden and close their micropyle which is the only entry point for sperm (Karas, 1997). Under good conditions brook trout have a very high rate of fertilization, averaging between 80 and 90 percent (Karas, 1997).

Females do not release all of their eggs at once and after one successful spawn they will proceed to dig a new redd to repeat the process (Karas, 1997). Females can deposit between 100 and 5000 eggs depending on their size (Karas, 1997). Duration of incubation varies according to water temperatures, being shorter in warmer waters and longer in colder (Karas, 1997). This generally means that more northern or higher elevation populations will have longer incubation times (Karas, 1997). As an example, eggs incubating in 40°F waters will require 103 days to hatch, while at 45°F they will only require 68 days (Karas, 1997).

Once hatched larvae will remain in the redd's gravel from 23 to 80 days, depending on temperature, until their yolk sac is fully absorbed (Karas, 1997). They begin to feed immediately after the yolk is absorbed, will be free swimming at 1.5 inches in length, and begin forming scales at 2 inches (Karas, 1997). After leaving the redd, the fry will stick close to stream edges among aquatic vegetation, woody debris, or other cover that will afford them protection from predators (Karas, 1997). As they grow larger, juveniles will likely migrate from their natal streams to more productive waters to feed (Karas, 1997). They may go to the main stem of rivers, beaver ponds and small lakes, vast bodies of fresh water, or all the way out to salt water in search of space to forage and grow (Karas, 1997)

Growth rate and age at maturity will vary depending on the environment (Karas, 1997). In general, males will mature earlier than females with some precocious males developing ripe gonads and spawning during their first year (Age 0; Karas, 1997). Female gonad ripening typically takes at least 12 months meaning the earliest they can first spawn would be at Age I, but Age II is the average (Karas, 1997). Some populations in the far north have such slow growth and maturation rates that individuals up to 7 years of age have been recorded to be sexually immature, while in other populations individuals may still display juvenile parr markings at first spawn (Karas, 1997).

Brook trout are short lived with respect to other members of the salmonidae family, living an average of only 4 years (Karas, 1997). There are exceptions to this with some populations regularly reaching 8 or 9 years old and some individuals estimated to be older than 20 (Karas, 1997).

Hybrids

Brook trout have been hybridized with several other closely related species in aquaculture settings, but little hybridization has been occurring in nature (Jansson, 2013).

Splake are the hybrid cross between a male brook trout and a female lake trout (*Salvelinus namaycush*) (Jansson, 2013). They are genetically stable and capable of reproduction, though wild spawning has rarely been recorded (Jansson, 2013). Splake possess a higher growth

Figure 3. Top three fish are examples of Tiger trout and the bottom fish is an example of a Splake. (Wikipedia – TyreeUM)

rate and live longer than either of the parent species (Jansson, 2013).

Tiger trout are the result of the crossing of a female brook trout and a male brown trout (*Salmo trutta*) (Jansson, 2013). These hybrids are almost always sterile and have high mortality, but the survivors are considered excellent game fish and are produced and stocked in a number of areas (Jansson, 2013).

Figure 4. An example of a Sparctic char. (Janny Bosman)

Sparctic char are the hybrid of a brook trout and an arctic char (*Salvelinus alpinus*) (Jansson, 2013). These hybrids grow faster and are more robust than either of the parent species and are thus popular in sport fisheries (Jansson, 2013). Some of these hybrids are fertile and natural spawning attempts have been witnessed, but were not successful because the attempts were made in a saltwater environment (Jansson, 2013; Richey, 2011).

Brook trout have been found to hybridize with bull trout in their introduced range, producing mostly sterile offspring (Montana FWP).

Feeding habits

Brook trout are opportunistic feeders and have been known to eat everything from insects to fish to small mammals and even plant matter (Karas, 1997). The composition of their diet will vary with the environment and season, but typically feed on prey drifting with the current in the water column or on the surface (Naiman et al, 1987). They are also known to have a greater propensity for picking prey directly off benthic substrate than other salmonids (Benjamin et al, 2013).

Small emergent fry up to an inch long will feed primarily on macroscopic crustaceans of Entomostraca; from 1 to 1.5 inches they will switch to insect larvae, primarily chironomid diptera; from 1.5 to 4 inches they will switch over to primarily *Ephemera* nymphs and Trichoptera larvae; from 4 to 8 inches they will feed on primarily terrestrial and aquatic insects; they begin feeding on small fish when they are between 8 to 12 inches; and once they are larger than 12 inches they will feed on anything they can fit in their mouth including larger fish, amphibians, reptiles, and small mammals (Karas, 1997).

Brook trout are visual predators and thus need light in order to feed (Naiman et al, 1987). They are most active in the early morning and late afternoon, but will be relatively inactive during the brightest part of the day in order to conserve energy and avoid predation (Karas, 1997). They have even been known to feed at night when there is sufficient moonlight (Karas, 1997).

Figure 5. Small Brook trout in a high mountain lake feeding on insects at the surface. (http://pristinefarmexperience.wordpress.com/)

Environmental optima and tolerances

Compared to other members of the salmonidae family brook trout are the least specialized in their habitat demands and as such can tolerate a wide variety of environmental conditions (Karas, 1997). Brook trout are equally at home in small streams, larger rivers, beaver ponds, large lakes, estuaries, and coastal marine environments (Karas, 1997).

Brook trout are cold water species and thrive in the northern half of the Northern Hemisphere, but range from northern most Quebec in Canada down to the northern parts of South Carolina and Georgia in the United States (Karas, 1997; Maine IF&W). They can survive in waters from 32°F to 72°F, but the range for optimum growth and survival is between 55°F to 65°F (Karas, 1997).

Brook trout have also developed a tolerance to acidic conditions since many of the habitats they colonized following the retreat of the continental ice sheets were coniferous forests, which decrease water pH due to tannic acid in their fallen needles (Karas, 1997). They can live in waters ranging in pH from 4.1 to 9.5 and have even been known to survive in waters as low as 3.4, but reproduction was severely impacted (Karas, 1997).

When living in rivers and streams, brook trout like to stay in areas of moderate flow, such as just above or below a set of rapids (Karas, 1997). This is because they want to expend as little energy on finding food as possible, allowing it to drift to them instead of searching it out like they would be forced to in slack water (Karas, 1997).

Biotic associations

Brook trout have been associated with a host of diseases and parasites, most of which are typically associated with fish culture operations. Wild fish populations are typically the harbourers of pathogens that are then passed to cultured fish through the water supply, but it is generally in cultured fish that we see the epizootic outbreaks (Warren, 1991).

Whirling disease (*Myxobolus cerebralis*) became of particular concern to several eastern states in the early 2000s when it was suspected to be introduced there by hatchery reared rainbow trout (*Oncorhynchus mykiss*) (Maryland DNR, 2006). Whirling disease is an internal protozoan parasite that infects the cartilage of the head and spinal cord and can cause cranial-spinal deformations and mortalities (Warren, 1991). It gets its name from the mad, tail-chasing behavior exhibited by some infected salmonids (Warren, 1991). Mortalities and visible symptoms of this disease are likely only to be seen in young and highly susceptible fish (Warren, 1991).

More commonly seen parasites of brook trout are the external copepods often called lice. There are three types of copepods likely to be encountered on a brook trout: the *Salminicola spp.* or gill lice; the *Argulus spp.* or freshwater lice; and *Lepeophtheirus salmonis* or sea/salmon louse (Warren, 1991, Trout Unlimited). These parasites rarely cause adverse effects or mortalities in host fish unless unusually large infestations occur (Warren, 1991). Brook trout have been shown to have decreased tolerance to high temperatures when sufficiently infested with *Salminicola spp.* (Vaughan and Coble, 1975).

There are many more diseases and parasites that can affect brook trout, but are outside of the scope of this report. Many state fisheries agencies as well as the US Fish and Wildlife Service publish texts on the subject that you may be able to request by phone or e-mail or find at a local library. The reference text I have used is the Sixth Edition of Diseases of Hatchery Fish written by James W. Warren and published by the US Fish and Wildlife Service in 1991.

Distribution

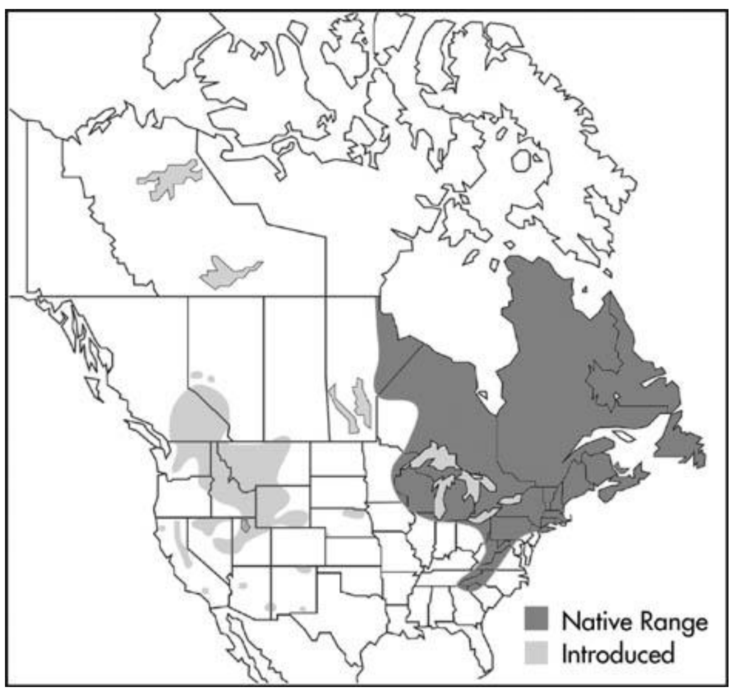

Figure 6. North American distribution of Brook Trout. (Maine IF&W)

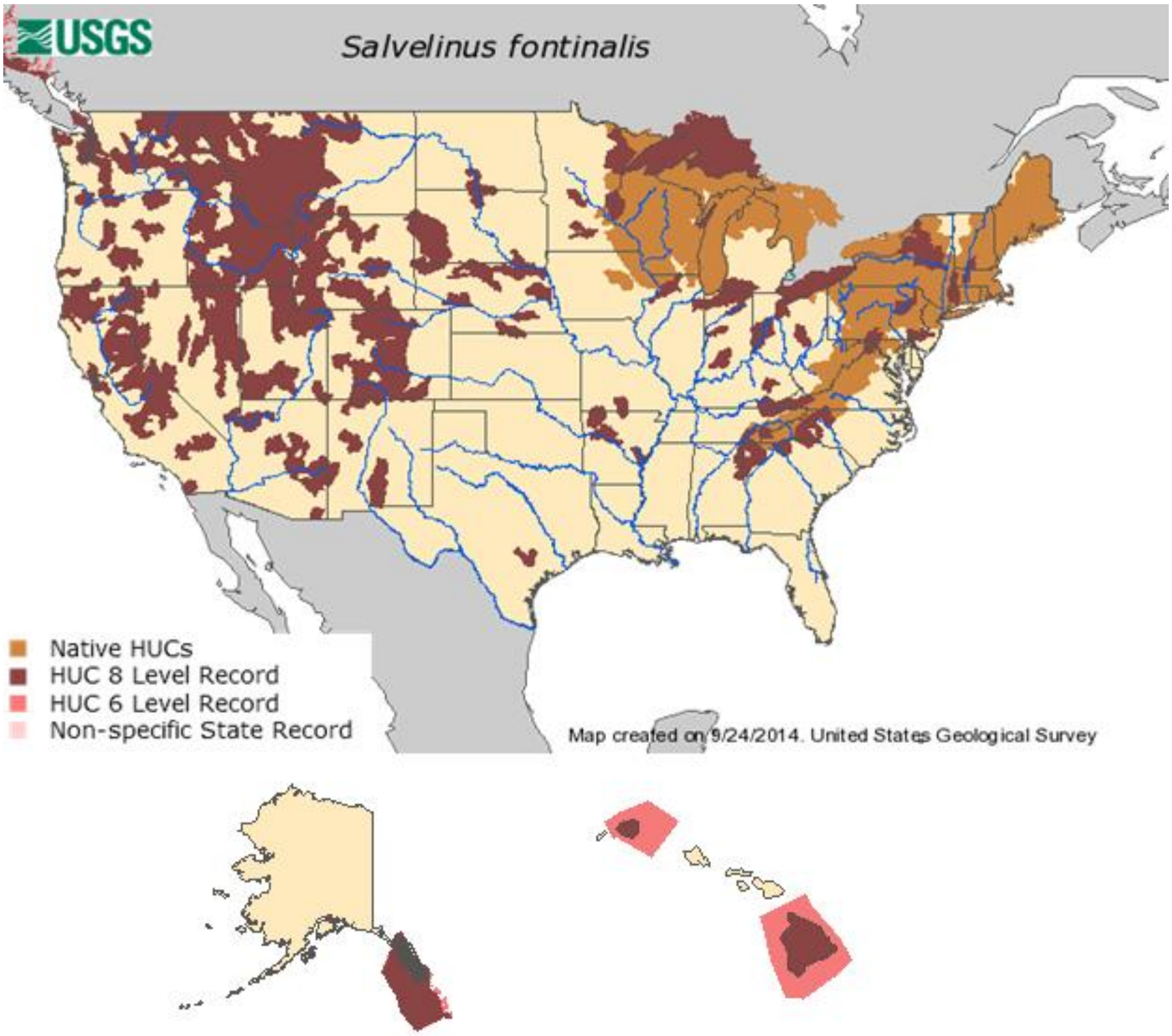

Figure 7. US distribution of Brook Trout reported by the US Geological Survey in 2014. (USGS)

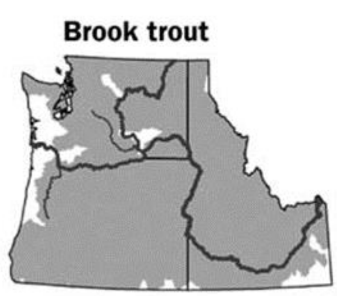

Figure 8. Brook Trout distribution by fourth field HUC in Washington, Oregon, and Idaho. (Sanderson et al, 2009)

The brook trout's native range goes from the northern areas of Quebec down to the northern parts of South Carolina and Georgia and from the coasts of Newfoundland in the east to Manitoba down to Minnesota in the west (Karas, 1997; Maine IF&W).

In North America, brook trout have been introduced intentionally for sport fishing purposes since the late 1800s and have established populations ranging from Southeast Alaska down to Texas (Fuller and Neilson, 2014). Global introductions of brook trout also began in the late 1800s and there are now established populations in many European countries, South America, Asia, Africa, and Oceana (Jansson, 2013).

Brook trout have been introduced to previously fishless high alpine lakes as well as lakes, streams, and rivers already inhabited by native salmonid species across the western US. In the Pacific Northwest, brook trout have extensive distributions including most endangered Pacific salmon habitats (Sanderson et al, 2009).

History of Invasiveness

Culture and transport of brook trout began in the 1850s and was initially done to enhance populations in its native range (Karas, 1997). Soon after, they began to be stocked in non-native waters of western North America and Europe (Karas, 1997). The first shipment of fertilized eggs reached Great Britain in 1869 with many subsequent shipments reaching other European nations in the following decades (Karas, 1997; Jansson, 2013). New Zealand and Australia were the next stop for brook trout, arriving in 1877 and 1908 respectively (Karas, 1997). Japan received its first US shipment of brook trout eggs in 1901 and India received theirs in 1963 (Karas, 1997). Brook trout have been stocked in seven South American countries since 1928 and have established populations in all but two (Karas, 1997). Africa was the last continent to receive brook trout and eggs were first shipped from England in 1949 and from the US in the 1955 (Karas, 1997). Most initial stocking efforts were not deemed successful, but with continued releases throughout the 20th century most sites established reproducing populations (Jansson, 2013).

Brook trout are easily raised in the hatchery setting and are hardy fish that can be transported great distances with generally high survival; this made them the perfect candidate for worldwide distribution (Karas, 1997). Their fast initial growth rate and high fecundity made them ideal settlers in introduced environments (Karas, 1997). Though primarily imported and stocked for sport fishing, brook trout also had their place on the fish farm for production and sale in the commercial market (Karas, 1997). Brook trout have also been used to replace native salmonids in waters that have become acidified because of their greater tolerance to low pH (Jansson, 2013).

Hatchery raised brook trout were commonly released into waters that were already home to healthy native trout populations (Karas, 1997). This has led to declines in native trout populations in many of the introduced watersheds (Karas, 1997).

Evidence of the brook trout's effects on native salmonids began to be recognized in the 1960s and since then stocking programs have been greatly diminished, though not entirely stopped (Karas, 1997). Several eradication and control projects have been attempted in various locations with limited success (Karas, 1997).

Being intentionally stocked, as well as being a popular fish among anglers, brook trout have only begun to be viewed as invasive relatively recently. This is especially true in the US, with many state agencies not including brook trout on their lists of aquatic invasive species.

Brook trout have subsequently invaded most streams which they have had access to and have become the most widespread and abundant non-native fish in the western United States (Benjamin et al, 2013).

Invasion Process

Pathways, vectors, and routes of introduction

The primary pathway of introduction for the brook trout is intentional stocking for the enhancement of sport fishing opportunities. Escapes from aquaculture facilities and hatcheries have also been recorded (Jansson, 2013).

In the early days of brook trout stocking, eggs and fry, sometimes even broodstock, were transported by any means available to their intended destination (Karas, 1997). Trains, ships, wagons, and mules were all used in the global spread of brook trout (Karas, 1997). Many times fish were released into waterways that appeared suitable while en route to their destination.

Nowadays, transport of brook trout for stocking is done primarily by specialized tanker trucks. Trade of eggs within the aquaculture industry is of global extent and many shipments are sent by air. Brook trout eggs, as well as many other fish species, can now be transported around the world quickly, easily, and with incredibly high survival rates. Juveniles and adults are also shipped around the world, but this is far less common because of the higher costs and risks

Figure 9. Top – Transporting fish eggs in milk barrels on a horseless carriage in the early 1900s. Bottom – Example of a modern fish planting truck (Maine IF&W; John Hageman)

associated with shipping free swimming live fish.

Brook trout eggs were initially supplied to interested culturists around the world by hatcheries in their native range in the northeastern United States (Karas, 1997). Once the receiving facilities of these initial shipments established stable aquaculture populations, they also began shipping eggs to other hatcheries (Karas, 1997). The primary route of introduction has been from the United States, but shipments from European nations have also been commonplace.

Non-authorized introductions by "bait bucket biologists" are also likely to have occurred throughout their non-native range, further ingraining the species into the landscape (Jansson, 2013).

Factors influencing establishment and spread

Brook trout are a very versatile fish with wide environmental tolerances, but they do have some requirements that influence whether they will establish in an introduced environment. Primarily, brook trout require cool, clear, and clean waters to survive (Karas, 1997).

The most importantly factor influencing the establishment of brook trout populations is temperature (Karas, 1997). If the introduced waters have temperatures outside of their optimum range, establishment of a self-sustaining population will be extremely difficult if not impossible. Warm waters present the biggest problem to brook trout because the warmer the water the lower the oxygen concentration (Karas, 1997). Brook trout populations in their native range have been extirpated due to rising water temperatures associated with the removal of riparian vegetation that provided shade (Karas, 1997). Brook trout eggs are also sensitive to temperature and anything above 53°F is lethal to the developing embryo (Karas, 1997).

Clear waters are also important to the successful establishment of brook trout populations. Being visual predators, if the waters are too turbid their ability to feed will be negatively impacted (Naiman et al, 1987). Reproduction requires a lot of energy and if a fish cannot feed at a sufficient capacity they will not have the energy to spawn successfully. Brook trout eggs can also be smothered if too much sediment accrues on them during the incubation period.

Though they are the most highly tolerant salmonid species to pH, many populations within their native range have been detrimentally effected by acidification of stream waters (Karas, 1997). Airborne pollution which causes acid rain as well as urbanization and mining operations all contribute to the increasing acidity of stream waters and areas severely impacted by these issues are unlikely to establish brook trout populations (Karas, 1997; Roberts, 2000).

Brook trout are territorial feeders and can compete successfully with many other fish, but some species are liable to cause issues for brook trout if in sufficient numbers. In particular rainbow trout (*Oncorhynchus mykiss*) have been known to outcompete brook trout for prime habitat (Karas, 1997). Brook trout may be unable to successfully establish a reproducing population if there is a large population of rainbow trout already present. It has also been shown that Chinook salmon juveniles (*Oncorhynchus tshawytscha*) can successfully displace larger brook trout from feeding territories (Macneale et al, 2009). The less competition there is from native fishes, the more likely a brook trout population is to establish.

High propagule pressures associated with stocking activities have aided in the establishment of many brook trout populations. Continued stocking in the face of initial failure has led to the establishment of many non-native brook trout populations in environments that they would have never been able to colonize naturally, even if they had had access (Karas, 1997).

Once a population has become established, the spread of brook trout in an open system is highly likely. Brook trout prefer the colder, clearer waters of headwater streams and will spread upstream from their point of initial release (Karas, 1997; Jansson, 2013). Brook trout will migrate when space and resources become limited; so if all suitable upstream habitats are at capacity, brook trout will then head downstream in their search for living space (Karas, 1997). This behavior can allow a single introductory population to spread throughout an entire river system given enough time.

Brook trout are highly capable of dispersing, possessing the ability to ascend slope gradients of up to 22 percent, vertical falls up to 1.3 meters, and complex falls up to 1.15 meters (ISSG). They have even been known to move through mires at high water flows, possibly gaining access to headwaters of adjacent drainages (Jansson, 2013).

Potential ecological and economic impacts

The economic impacts of brook trout invasions are generally positive due to their desirability in the sport fishing community (Jansson, 2013). Anglers spend money on bait, tackle, travel, lodging, dining, fishing licenses, guides, etc., all of which add to local economies (Jansson, 2013). The culture and stocking of brook trout also provide job in the hatcheries themselves, in feed production, in the manufacture of hatchery related equipment, etc.

Negative economic effects may be incurred through the brook trout's detrimental effects on native fish populations. If the non-native brook trout is causing a decline in a more valuable native species, such as Chinook salmon, the economic benefits they bring may be offset by the economic losses suffered from the loss of the more valuable species.

Brook trout are the most abundant exotic fish species in spawning and rearing habitat of chinook salmon in the Columbia River Basin (Levin et al, 2002). They have been seen to easily outcompete juveniles for feeding territory and have been known to feed directly on both eggs and fry (Levin et al, 2002; Macneale et al, 2010). Interestingly, smaller juvenile chinook have been seen to successfully fend off larger brook trout encroaching on their feeding territory, suggesting that they are more aggressive (Macneale et al, 2010). Unfortunately, this higher aggression can only make up for a limited size discrepancy and with most brook trout being much larger than juvenile chinook they maintain the overall competitive advantage (Macneale et al, 2010).

Levin et al (2002) reported a 12 percent reduction in survival of juvenile chinook in streams containing brook trout compared with those without in the Snake River basin. It was also reported that habitat restoration projects had little effect of juvenile salmon survival when brook trout occupied the same region; whereas in the absence of brook trout there was a positive association of chinook survival with habitat quality (Levin et al, 2002).

Due to their similar life histories and habitat requirements, brook trout invasions often exert the greatest impact on native salmonid populations. It is believed by some scientists that brook trout are one of the primary causes of decline in populations of cutthroat and bull trout in western North America (Rieman et al, 2006).

Brook trout compete with cutthroat and bull trout directly for food and space, as well as predate on juveniles (Lepori et al, 2012; Rieman et al, 2006). These competitive interactions have led to variable results; from coexistence in some streams to complete displacement of natives in others (Warnock and Rasmussen, 2013).

It is thought that habitat heterogeneity and slight differences in niche preferences between brook and native trout allow coexistence to occur where it does (Rieman et al, 2006). Brook trout tend to inhabit the slightly warmer, deeper, and slower flowing reaches that have smaller substrate and ample bank cover (Rieman et al, 2006). Whereas, natives occupy the cooler, swifter regions with larger substrate higher up the streams (Rieman et al, 2006). Brook trout are also known to feed on benthic prey more often than native salmonids providing some separation in food resource use (Lepori et al, 2012).

Brook trout have also been known to hybridize with native bull trout producing mostly sterile hybrids (Montana FWP). Though the threat of introgression is low due to the hybrids sterility, energy is sapped from the native bull trout population through these "wasted" reproductions (Montana FWP).

Brook trout exert similar competitive pressures that result in reductions and displacements of fishes around the globe, such as; golden trout (*Oncorhynchus aguabonita*), brown trout (*Salmo trutta*), and dolly vardon (*Salvelinus malma*), the last two have also been known to hybridize (ISSG). Brook trout have also been theorized to have prevented the establishment of populations of stocked grayling (*Thymallus thymallus*) due to their aggressive nature (Fuller and Neilson, 2014).

The ecological effects of a brook trout invasion can be farther reaching than one may expect. Not only will brook trout affect other resident fishes, but can also impact other local fauna such as aquatic and terrestrial invertebrates, spiders, amphibians, and even birds and bats (Benjamin et al, 2013).

Brook trout generally occur at higher densities than native salmonids, which means they consume more resources than the native population would (Lepori et al, 2012). Insect emergence was 36 percent lower in streams containing brook trout than from similar ones where brook trout were not established (Benjamin et al, 2013). This lowered emergence was projected to reduce riparian spiders by 6 to 20 percent (Benjamin et al, 2013). It is also theorized that the loss in total emergence flux will impact bird and bat populations that feed heavily on these insects (Benjamin et al, 2013).

Figure 10. A brook trout (lower fish) and a native Yellowstone cutthroat trout (*Oncorhynchus clarkii bouvieri*) (upper fish) together in the wild. (Fish Eye Guy Photography)

Predation by brook trout has also severely impacted many amphibian populations in their introduced range (ISSG). This was mainly due to the brook trout's introduction to previously fishless lakes and specific reductions due to brook trout have occurred in the following species: Chiricahua leopard frog (*Rana chiricahuensis*), boreal chorus frog (*Pseudacris maculata*), Colombia spotted frog (*Rana luteiventris*), wood frog (*Rana sylvatica*), tailed frog (*Ascaphus truel*), cascade frog (see *Rana cascadae*), Pacific tree frog (*Pseudacris regilla*), Iberian frog (*Rana iberica*), tiger salamander (*Ambystoma tigrinum*), northwestern salamander (*Ambystoma gracile*), long-toed salamander (*Ambystoma macrodactylum*), boreal toad (*Bufo boreas*), palmate newt (*Triturus helveticus*), alpine newt (*Triturus alpestris*), marbled newt (*Triturus marmoratus*), and mountain yellow-legged frog (*Rana muscosa*)(ISSG).

Brook trout are also thought to produce modifications in benthic zooplankton, macroinvertebrate, and algal communities due to top down cascading trophic interactions (ISSG).

Management Strategies and Control Methods

There are a number of potential ways to manage and control populations of invasive brook trout. Depending on the desired outcome of a management plan a variety of strategies may be employed.

In situations where a non-native brook trout population is more ecologically detrimental than they are worth socio-economically, most managers would hope to eradicate it completely (Britton et al, 2011). When attempting to eradicate an entire population managers have two major options; physical removal or chemical treatment (ISSG). Physical removal of a population would mean either netting them out in large numbers, electrofishing them out, or even using classic hook and line methods (Britton et al, 2011; ISSG). Physical removal requires a lot of time, effort, and often times man power, but typically poses the least risk to non-target species (Britton et al, 2011). Chemical treatment generally requires less work and has a higher probability of completely eradicating a target population, but the down side is that chemical treatment will also kill everything else living in the treated habitat and can also pose a risk to human health as well (Britton et al, 2011). Despite the risks, the use of rotenone to eliminate unwanted fish species from water bodies has been common throughout the past century (Britton et al, 2011). Successes have been had using both methods, or some combination of the two, but eradication endeavors are usually only successful in moderately small, closed systems such as small lakes and ponds (Britton et al, 2011).

Figure 11. Applying rotenone to a water body in order to eradicate invasive fish species. (Environment Agency)

For areas where complete eradication is either physically or economically not viable, control or containment methods are the only other option beside the "no action" approach (Britton et al, 2011). Controlling a population involves removing individuals from a population in order to suppress abundance and reduce recruitment (Britton et al, 2011). This is typically done by physical means such as, trapping, netting, and electrofishing and most likely has to be performed at regular intervals to keep abundances down (Britton et al, 2011). There has also been recent attempts at controlling populations using "daughterless technology" which involves the release of genetically engineered fish that produce a biased sex ratio towards males when they mate (Britton et al, 2011; Idaho F&G). This will hopefully reduce the population's ability to reproduce and result in negative population growth rates (Britton et al, 2011; Idaho F&G)

Containing populations requires the construction of fish passage barriers that prevent the spread of an invader to previously uninvaded areas or areas where non-natives have been removed (Britton et al, 2011). Containment poses problems because constructed barriers not only prevent the movement of invaders, but also native species (Britton et al, 2011; Peterson et al, 2008). Barriers can isolate populations of native fish like cutthroat trout causing loss of genetic diversity, reduced population resilience, and local extinctions (Peterson et al, 2008). Peterson et al (2008) investigated the tradeoffs between leaving these barriers in place, thus continuing western cutthroat trout (*Oncorhynchus clarkii lewisi*) population isolation, or removing them and thus exposing those populations to brook trout invasion. They suggested that western cutthroat trout should be able to resist brook trout invasions and would gain considerable advantages if the isolated populations were reconnected (Peterson et al, 2008). However they cited that there is a lack of empirical data to support the claim that connected, migratory cutthroat trout populations are better able to resist invasions and that further research is needed on the subject (Peterson et al, 2008).

In some cases the most viable approach is the "no action" option (Britton et al, 2011). This approach is exactly what it sounds like and is unfortunately one of the most commonly employed management approaches (Britton et al, 2011). Many times invasions are just too advanced and there is no feasible way to manage the population until new techniques or technologies are discovered (Britton et al, 2011). For the most part non-native brook trout populations were established many years ago, but the prevention of new invasions is still an important management strategy today. New invasions may occur through spread from previously established populations through the removal of some sort of barrier, illegal stocking activities, aquaculture escapes, or possibly even new authorized stocking efforts, though this is rare given the current knowledge of the detrimental effects associated with such actions (Peterson et al, 2008; Jansson, 2013; ISSG). Several publications have been produced that aim to provide managers with guidelines to mitigate these potential sources of new introductions and to prepare them for rapid response should one occur (Britton et al, 2011; ISSG). In many cases, educating the public and those handling potential invaders is the only viable form of preventative action.

For a more detailed account of management and control strategies please see "Managing non-native fish in the environment" by Britton et al (2011).

Literature Cited

Almeida D, Grossman GD (2012) Utility of direct observational methods for assessing competitive interactions between non-native and native freshwater fishes. Fisheries Management and Ecology 19:157-166

Benjamin JR, Lepori F, Baxter CV, Fausch KD (2013) Can replacement of native by non-native trout alter stream-riparian food webs? Freshwater Biology 58:1694-1709

Britton JR, Gozlan RE, Copp GH (2011) Managing non-native fish in the environment. Fish and Fisheries 12:256-274

Fuller P, Neilson M (2014) *Salvelinus fontinalis*. USGS Nonindigenous Aquatic Species Database

Jansson K (2013) NOBANIS-Invasive Alien Fact Sheet-*Salvelinus fontinalis*. Online Database of the European Network on Invasive Alien Species

Karas N (1997) Brook Trout. Lyons and Buford, New York

Lepori F, Benjamin JR, Fausch KD, Baxter CV (2012) Are invasive and native trout functionally equivalent predators? Results and lessons from a field experiment. Aquatic Conservation: Marine and Freshwater Ecosystems 22:787-798

Levin PS, Achord S, Feist BE, Zabel RW (2002) Non-indigenous brook trout and the demise of Pacific salmon: a forgotten threat? Proceedings of the Royal Society of London B 269:1663-1670

Macneale KH, Sanderson BL, Courbois JYP, Kiffney PM (2010) Effects of non-native brook trout (*Salvelinus fontinalis*) on threatened juvenile Chinook salmon (*Oncorhynchus tshawytscha*) in an Idaho stream. Ecology of Freshwater Fish 19:139-152

Maryland Department of Natural Resources (2006) Maryland Brook Trout Fisheries Management Plan

Morinville GR, Rasmussen JB (2008) Distinguishing between juvenile anadromous and resident brook trout (*Salvelinus fontinalis*) using morphology. Environmental Biology of Fishes 81:171-184

Naiman RJ, McCormick SD, Montgomery WL, Morin R (1987) Anadromous Brook

Charr, *Salvelinus fontinalis*: Opportunities and Constraints for Population Enhancement. Marine Fisheries Review 49:1-13

Peterson DP, Rieman BE, Dunham JB, Fausch KD, Young MK (2008) Analysis of trade-offs between threats of invasion by nonnative brook trout (*Salvelinus fontinalis*) and intentional isolation for native westslope cutthroat trout (*Oncorhynchus clarkii lewisi*). Canadian Journal of Fisheries and Aquatic Sciences 65:557-573

Richey JD (2011) Sparctic Char: Strange Nighttime Saltwater Spawners from Europe! FishWithJD.com

Rieman BE, Peterson JT, Myers DL (2006) Have brook trout (*Salvelinus fontinalis*) displaced bull trout (*Salvelinus confluentus*) along longitudinal gradients in central Idaho streams? Canadian Journal of Fisheries and Aquatic Sciences 63:63-78

Roberts J (2000) *Salvelinus fontinalis*. Animal Diversity Web

Sanderson BL, Barnas KA, Rub AMW (2009) Nonindigenous Species of the Pacific Northwest: An Overlooked Risk to Endangered Salmon? BioScience 59:245-256

Vaughan GE, Coble DW (1975) Sublethal effects of three ectoparasites on fish. Journal of Fish Biology 7:283-294

Warnock WG, Rasmussen JB (2013) Abiotic and biotic factors associated with brook trout invasiveness into bull trout streams in the Canadian Rockies. Canadian Journal of Fisheries and Aquatic Sciences 70:905-914

Warren JW (1991) Diseases of Hatchery Fish Sixth Edition. US Fish and Wildlife Service

Other Key Sources

Aquatic Nuisance Species (ANS) Task Force.
http://www.anstaskforce.gov/experts/expertlist.php?expertprimarystate=WA

British Columbia.
http://www.env.gov.bc.ca/fw/fish/sport_fish/#BrookTrout

Idaho Department of Fish and Game.
http://www.fws.gov/Columbiariver/nwfcc2012/presentations/S1_Jeske.pdf

Invasive Species Specialist Group (ISSG) - Global Invasive Species Database.
http://www.issg.org/database/species/ecology.asp?si=1226&fr=1&sts=sss&lang=EN

Integrated Taxonomic Information System.
http://www.itis.gov/servlet/SingleRpt/SingleRpt?search_topic=TSN&search_value=162003#

King County.
http://www.kingcounty.gov/environment/animalsAndPlants/biodiversity/threats/Invasives.aspx

Maine Department of Inland Fisheries and Wildlife.
http://www.mainebrooktrout.com/?page_id=77

Montana Fish, Wildlife, and Parks.
http://fwpiis.mt.gov/bulltroutid/training/training7.htm

Trout Unlimited.
http://www.wisconsintu.org/Default.aspx?alias=www.wisconsintu.org/gilllice

Washington Department of Fish and Wildlife.
http://wdfw.wa.gov/fishing/washington/Species/1261/

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Current Research and Management Efforts

Current research is investigating a myriad of effects that brook trout are having on the ecosystems of their invaded range as well as new ways to mitigate those effects and control populations. Though much research has shown the detrimental effects invasive brook trout have on their introduced ecosystems, few management efforts are in effect and many state and federal agencies continue to stock them in non-native waters. Their value as sport fish oftentimes outweighs their negative impact as a foreign invader. Management of brook trout is primarily seen where another species is in imminent peril and will become extinct if the brook trout are not removed. This has often been in the small, high alpine lakes which were previously fishless before stocking of brook trout, as well as, small tributaries that are important breeding grounds for endangered native salmonids. Direct observation of competitive interactions between brook trout and native salmonids will likely become more prevalent in order to more clearly understand the behaviors associated by each in these encounters (Almeida and Grossman, 2012). More technologically advanced control methods involving genetics will likely become perfected in the coming years and hopefully lead to more effective eradication and control methods for large open systems. Until then, brook trout will remain a common resident of our Pacific Northwest waters, for better or for worse.