Invasive Species of the Pacific Northwest

Brown Trout; and their Ecological Impacts as an Invasive Species

By Austin Burrill
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Figure 1. Brown trout I caught during the summer of 2014 in a small tributary (Ruby River) to the Beaverhead River in Southwestern Montana by means of fly angling.

Figure 2. Sea run Brown Trout, or Sea Trout, which is actually the same species. They are genetically homogenous, and many populations reserve the option to be migrate out to sea.
Introduction

Brown trout (*Salmo trutta*) have long been a favorite sport-fish among anglers, and have been transported primarily on the basis of recreational fishing. They belong to the order Salmoniformes, and are classed with the family Salmonidae. This species is a close relative of the Atlantic salmon (*Salmo salar*), and both originate from Europe, but Brown trout have a native range that also includes North Africa and Western Asia. Now Brown Trout exhibit a worldwide distribution, as they have been introduced far outside of their native range(s) (Klemetsen 2003). Though they are not commonly thought of as invasive species by the non-scientific community, they have been observed to migrate far beyond their initial introduction location(s). Interestingly, some populations or subsets of populations exhibit anadromy, at which point they are called Sea Trout. Since some brown trout population are highly migratory, they are not limited to one river system. This allows the species to propagate far beyond their initial introduction locale. During their spawning migrations, they have been observed to move an average of over 100 meters per day (Saraniemi 2008). As Brown trout share characteristics with endemic trout species, they have been documented to disrupt natural ecosystem interactions, and in severe cases cause extinction. This species has been shown to displace native species, compete for food, or directly predate on species of concern (Townsend 1996). They are also known for hybridizing with native Brook Trout (*Salvelinus fontinalis*) resulting in sterile offspring. Here we will investigate general information about the invasive Brown trout, and look at how they currently impact the Pacific Northwest.

Figure 3. Brown Trout photo credit http://www.nps.gov/media/photo/
Brown Trout; and their Impacts as an Invasive Species

Figure 4. Generic trout body plan and basic anatomy.

**Diagnostic information**

*Order.* Salmoniformes

*Family:* Salmonidae

*Genus:* Salmo

*Species:* trutta

*Common names:* Brown trout, German Brown, Sea Trout, Loch Leven Trout

**Identification**

Identification of brown trout has not been a cause of concern, which is unlike the other trout, salmon, and char species. Though juveniles remain particularly difficult to identify because their characteristics are not yet pronounced. Mature Brown trout are characterized by an overall brown body color, with large pronounced black spots, which are more concentrated dorsally. These spots are often said to have a maroon “halo” around them, but these trout have fair genetic plasticity and are often observed to vary phenotypically even within the same stream network. Interestingly, Sea trout have long been considered a different species. It has been said that populations of sea-run Brown trout are difficult to distinguish from Atlantic salmon, as Sea Trout have a vastly different life cycle that involves an anadromous form. Sea run Brown Trout spend anywhere from 1-3 years at Sea before making an upstream migration towards their respective spawning grounds. Brown trout are commonly observed in the 12-20 inch range, and sexually mature males often have exaggerated jaws, or “kype.”
Life-history and basic ecology:

Life cycle

Feeding habits: juvenile brown trout feed primarily on insect larvae and small crustaceans. As brown trout age, they become more carnivorous and tend to target larger prey items such as other fishes (including cannibalism), mice, small birds, crayfish, etc. This feeding behavior results in competition between brown trout and other species of interest, given their predatory nature. Most brown trout become sexually mature between ages 1 and 3, though some brown trout have been observed living 10 years or more. Brown trout are iteroparous, but the stress resulting from reproduction often results in mortality.

Figure 4. Basic Trout lifecycle, starting as eggs and ending as sexually mature spawners.

Reproductive strategies:

Brown trout tend to spawn in the fall, before the high water season, and they often use temperature, water levels, and changes in sunlight as indicators of spawning time. This ensures that when the eggs hatch, in approximately 100 days, that there will be sufficient water.

Conversely, Steelhead, which are native to Washington, tend to spawn in early Spring which subjects the juveniles to low water conditions which brings with it a litany of problems involving temperatures that fall outside of the fish’s optima/tolerance, decreased dissolved oxygen, and low water conditions resultant of either drought or irrigation. As such, Brown trout share
spawning times with Pacific salmon species in the Northwest as well as Cutthroat trout and endemic char here in Washington. This ensures that the fish will emerge from the gravel closer to peak flow as opposed to the minimum flows as experienced in Pacific Northwest summers. Brown trout follow suit among other trout, salmon, and char species, as they are highly fecund, and they exhibit an egg burying strategy (Often less than 10 inches deep). As the trout sexually mature, they will develop what is known as kype, or exaggerated jaws. There is inherent sexual dimorphism here, and larger kype is hypothesized to increase male fitness. Larger males tend to be preferred over their smaller counterparts, but this doesn’t stop younger sexually mature males from participating. It has often been observed that smaller males will rush in and fertilize a females nest (or redd), despite there being a larger male at the ready.

Environmental optima and tolerances:

Brown trout have been observed to have higher temperature tolerances than other species of trout. Atlantic salmon are most resistant to higher temperatures, followed by Brown trout, then Arctic Char (Salvelinus alpinus). Ideal incubation temperatures are between 8-10 C for Brown trout. It has been observed that adult brown trout perform better than other trout species at higher temperatures. This higher temperature tolerance is a great advantage to the species given that trout survival are very sensitive to temperature shifts that are outside of their optimal range. Considering climate change, temperature may greatly influence brown trout distribution in the near future. Optimal incubation temperatures for Brown trout reside between 2 and 13 C. Their incubation tolerance range is between 0 and 13 C. As far as free living, or post juvenile forms of the species go, the ideal water temperature is in the range of 7 to 15 C and their tolerance resides between 0.4-4 and 19-26 C (Elliot et al 2010). Oxygen levels between 5 to 9 ppm dissolved give an optimal range, at temperatures between 5 and 15 C the optimal dissolved oxygen level is subject to fluctuation though, and is highly variable as such. Brown trout perform well under a pH that ranges from 5 to 9.5 (USGS 1986). Brown trout, especially in smaller to mid sized streams polarize towards cover, given the opportunity. Cover is one of many environmental variables that can serve to enhance recruitment in brown trout streams (Eklov 1998).

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<thead>
<tr>
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<th>Salmo salar</th>
<th>Salmo trutta</th>
<th>Salvelinus alpinus</th>
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<td>Lower Upper</td>
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<td>Eggs</td>
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<td>Feeding</td>
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<td>0.4–4 19–26</td>
<td>0.2 21–22</td>
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Figure 5 lists the lower and upper temperature (Degrees Celsius) tolerance bounds for Brown Trout, Atlantic salmon, as well as Arctic char. Used from: Temperature requirements of Atlantic salmon Salmo salar, brown trout Salmo trutta and Arctic char Salvelinus alpinus: predicting the effects of climate change (Elliot et al 2010).
During the pre-spawning period, in early summer, brown trout were found to travel an average of 348 meters a day. During spawning they moved an average of 160 meters, and lastly during winter they were observed to move only 23 meters a day (Saraniemi 2008).

Female Brown trout (hens) deposit eggs into redds in the same way as Pacific salmon species, and have a preference for substrate between 4 and 40 cm (USGS 1986). The female digs the red with her caudal fin, and she releases the eggs into the red just before fertilization the male (buck). The incubation periods are highly variable across the species’ native and invaded ranges.

**Biotic associations**

Whirling disease (Myxobolus cerebralis) is a pathogen that produces a potent neurotoxin, and is found in the same European streams as Brown Trout. This parasite infects Tubifex worms, which are ingested by trout and allow the parasites to jump hosts. Trout infected by the disease commonly exhibit “whirling” behavior, as a result of spinal degeneration, this will typically result in death. As Brown Trout co-evolved with this pathogen, they evolved an immunity that was not commonly shared by other naïve trout species. Once the parasite found its way into stocking programs that harbored Rainbow trout, the disease spread rampantly as preventative protocols were essentially nonexistent at this time. The only signs of whirling disease occur after the entire hatchery brood has been subjected to the pathogen. Living in the same environment has served as a huge advantage to brown trout, as they have been under extensive selection to evolve immunity to M. cerebralis. For example I look to the Madison river, where Whirling disease all but decimated the river’s historically healthy rainbow trout population. This opened up significant niche opportunities to Brown Trout, which soon flourished. Though rainbow trout populations have been observed to develop immunity to this pathogen, the cumulative effects of the disease are still largely detrimental. Brown trout have myriad biotic associations, but this particular case exemplifies a commensal pathogen that Brown trout can carry, and transmit to vulnerable species.

*Current geographic distribution and distribution in the PNW and the United States*
Figure 6 is a map of brown trout that have been found in coastal tributaries to the Columbia river. Two brown trout were found well outside of their original stocking programs.  


Figure 7 Is a map of Brown trout occurrences in the United States via:  


One study found two brown trout in tributaries to the lower Columbia river, one in Washington and one in Oregon (Bisson 1986). The closed circles indicate the location of the brown trout (Figure 7). These introductions were predicted to be the result of stocking programs, as no coastal populations have been found in the Pacific Northwest to date. Seeing that brown trout are appearing far outside of their stocked range has made this discovery significant. It is likely that Washington will see an influx of established brown trout populations in the near future. It is evident that brown trout inhabit an extensive range of the United States. Yet maps such as these only indicate the current locations where known brown trout populations reside. If this were a map of self sustaining brown trout populations the distribution would be a lot smaller, especially in Washington state. Washington isn’t currently home to sustainable populations of brown trout, and occurrences are thought to be resultant of stray hatchery fish

History of invasiveness

Brown trout have been stocked extensively on behalf of the angling community. Brown trout provide extensive economic value, and their introductions have been largely encouraged in the past. Brown trout are often referred to as German browns, as most strains of brown trout in the United states originated from German stocking programs. Many stocks are naturally reproducing, and brown trout have established populations in a majority of states in the US. Brown trout have a nearly worldwide distribution, and this value is only increasing as a result of their popularity. They demonstrate their ability to establish populations time and time again.
Invasion process

Pathways, Vectors, and Routes of Introduction:

Brown trout have been traditionally introduced via stocking programs. As such, the primary pathway for Brown trout introduction is that of stocking for sport fisheries. Bucket biologists have also been known to further propagate invasions, but state run as well as private stocking programs have been chiefly responsible for the influx of brown trout in the United States. Many of these programs have no regard for endemic species that will have to compete for the same resources. Recreational benefits continue to be a key driver in the propagation of brown trout, as such there is no significant effort to impede the march of the Brown trout.

Establishment and Spread:

For trout species to establish, a number of criteria must be met. The water must be suitable to the species, ie it doesn’t exceed (citation needed). Whereas spread is determined primarily based on stream connectivity. If the fish are stocked above an impasse, the likelihood of their spread is greatly diminished. Conversely if the stream is connected to others, it is more likely that the fish will occupy a range that is much greater than their initial introduction location. Another key component in invasion biology, are the characteristics of the invader. Host genetics have been shown to greatly influence the success or failure of establishment. Brown trout with genetics that are more similar to wild populations have been demonstrated to have increased invasion success. Host characteristics such as environmental tolerances, and rate of juvenile development have been associated with the successful invasion of Patagonia, where Atlantic salmon were ill-adapted (Valiente 2010). Juvenile Brown trout develop at a greater rate, than salmon species in the first year. This earlier maturation allows for earlier exploitation of resources, which allows for increased likelihood of establishment. Brown trout are known to migrate across large distances independently, but anglers have been reported to transport brown trout for the purpose of fishery enhancement.

Potential ecological and/or economic impacts

Predicted increases in temperature (caused by climate change) in the Pacific Northwest are predicted to further hinder Steelhead, as well as other Pacific salmon species’ reproductive successes (Wade 2013). As global temperatures increase, new niche opportunities will present themselves to Brown trout, and it is predicted that their range will be shifted northerly. Considering how vulnerable trout are to heat stress during early development, environments that may be well within the trout species’ current optimal range will likely see a polarization towards warmwater species. Washington may become a host to self-sustaining Brown trout populations as temperature regimes shift. In Yellowstone National Park, predictions have been made that as temperatures increase, Yellowstone cutthroat populations will decrease, and that invasive species will fill in the unoccupied niche (Al-Chokhachy 2013). The lower Yellowstone River is already host to a significant spawning brown trout population as well.

Another interesting study looked at how Brown trout influenced the growth of other species. It was found that in sympatry with brown trout, char grew more slowly (Forseth 2003). This is a very direct impact, and is reason for concern in watersheds that have endemic char. Washington State has both Bull Trout (Salvelinus confluentus) as well as closely related Dolly Varden (Salvelinus malma). Then again, in a Norwegian stream it was found that when the endemic Alpine Bullhead (Cottus poecilopus) was present that brown trout fed in
areas that put them at heightened risks of predation. As such, characteristics of the invader, members of the recipient indigenous or established population, as well as the environment, all factor into the outcome. The outcome is either successful or failed establishment, and important to the idea of establishment is propagule pressure, which is the number of discreet introduction events, which may or may not result in the establishment of the species. The stocking industry often serves to increase propagule pressure, as many stocking programs plant trout annually to ensure good catches.

It is generally assumed that introducing a non-native species to an environment with numerous endemic species would be deleterious to the recipient ecosystem. Yet in several shallow New Zealand lakes, it was found that the addition of non-native Brown and rainbow trout didn’t alter the lakes original invertebrate composition on any appreciable level, which was found to directly contradict findings in North American and European lakes. The lakes studied in America and Europe had dramatic invertebrate composition shifts after the introduction of trout (Wissinger 2006). These lakes exemplify that environmental characteristics determine whether the invasive species serve as a detriment or not. Characteristics of the invader are of limited importance, as the results of an invasion depend on more than invader characteristics.

Most studies that have determined brown trout to be harmful involve conspecifics. Findings indicate that brown trout harm populations of native salmonids through direct competition for food or space, and more directly in cases of Brown trout preying on endemics (McHugh 2006). So the introduction of Brown trout to North America has certainly caused damage, but the extent of the impact is largely unknown. Though brown trout can be introduced without any observable damage, each successfully established population can serve as invasion hub. This can allow the species to further migrate into naïve ecosystems either independently or as a result of human effort (ie. bucket biologists or a secondary stocking program). Brown trout are very successful at establishing new populations, as has been observed throughout their native European range. An interesting and well-known example of a brown trout invasion occurred in New Zealand. Brown trout were introduced to New Zealand over 100 years ago, and populations have since flourished. Brown trout have displaced and even been associated with the extinction of species endemic to New Zealand (Townsend 1996). As such, they have been the focus of extensive study. It has been said that the effects of brown trout are in fact reversible (Townsend 1996), and that normal biotic interactions could return given the removal of the invader.

Invasive species have been likened to a smoking gun in popular media (citation), but in reality the demise of most species is in fact resultant of interactions with the invader, but also due to habitat degradation, exploitation, and climate change, which alters previously suitable habitat. The term “invasive” has come to carry negative connotations, and the potential beneficial ecosystem services provided by invasive species are not well known. One study found that most anglers believed that their local rivers weren’t in need of extensive stocking programs, and that the population was self-sustaining. The reality of the issue was that extensive stocking programs were in place to ensure good catches (Baer 2010). Since sport fisheries are an integral part of numerous local economies, it is worth noting that Brown trout provide great economic benefits despite serving as potential threat to native biotic interactions. This complicates the issue, as stopping Brown trout stocking programs will not only have economic repercussions, but will also have social impacts. Brown trout have characteristics that make them an ideal invader, and their proximity to the Pacific Northwest has certainly made them a concern for Washington streams. Seeing stray brown trout appear along the Columbia river is reason for increased concern for Native Washington salmonids. Management strategies and control methods:
So far, there is no major effort to extirpate brown trout from the Pacific Northwest, or other locations for that matter. Stocking programs for brown trout still exist, and brown trout are a highly valued sport fish among anglers and they have cultural significance among fishing communities. Eradication is often seen as an infeasible goal in cases where the invader is so widespread, and many such eradication efforts have failed miserably.
Literature Cited


Elliott, J. M., & Elliott, J. A. (January 01, 2010). Temperature requirements of Atlantic salmon Salmo salar, brown trout Salmo trutta and Arctic charr Salvelinus alpinus: predicting the effects of climate change. *Journal of Fish Biology, 77*, 8.)

Valiente, A. G., Ayllon, F., Nuñez, P., Juanes, F., & Garcia-Vazquez, E. (January 01, 2010). Not all lineages are equally invasive: genetic origin and
life-history in Atlantic salmon and brown trout acclimated to the Southern Hemisphere. Biological Invasions, 12, 10, 3485-3495.


Other Resources


http://tweedfoundation.org.uk/tweedstart/html/fishes.html (figure 2)

http://whiterivertroudiva.net/uploads/2013/10/trout-fish-anatomy.jpg (figure 3.)

http://www.nps.gov/media/photo/ (figure 1)

http://www.nps.gov/media/photo/


Expert contact information in PNW

Julian Olden
Associate Professor, Aquatic & Fishery Sciences
olden@u.washington.edu, 206-616-3112

Thomas P. Quinn
Professor, Aquatic & Fishery Sciences
tquinn@u.washington.edu 206-543-9042

Fish and Wildlife Commission

Miranda Wecker, Naselle
(Western Washington position, Pacific County)
Occupation: Director of the Marine Program, UW Olympic Natural Resources
Current research and management efforts:

Brown trout are still stocked as part of the sport fishing industry, despite further potential invasions. Comprehensive research as to the cumulative impacts that invasive brown trout have on endemics is limited, as it’s impossible to know the extent of their damage. Brown trout will likely continue to be stocked as part of the sport fishing industry, though efforts have been made to avoid introducing brown trout into new environments. In many streams and lakes, the prospects of extirpating brown trout are poor.