Assessing and Mitigating the Impact of a Major Rainbow Trout Escape on the Wild Salmon and Trout Populations of the Mourne River System, Northern Ireland

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NON-NATIVE SPECIES RAPID RISK ASSESSMENT (NRRA)

Rapid Risk Assessment of: *Oncorhynchus mykiss* (Walbaum) – Rainbow trout in the River Mourne, Northern Ireland

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Introduction:
The rapid risk assessment approach is used to assess invasive non-native species. It is primarily used in situations where urgent management actions are required. It can also form a foundation for medium to longer term actions.

1 - What is the principal reason for performing the Risk?

Response: To assess the risk associated with the escape of 300,000 +, all-female triploid rainbow trout into the River Mourne on the 22nd /23rd August 2017. The assessment is being carried out on behalf of the Loughs Agency, 22 Victoria Road, Londonderry, Northern Ireland

2 - What is the Risk Assessment Area?

Response: River Mourne, Northern Ireland and its 14 main tributaries: the Burn Dennet, Deele, Finn, Glenelly, Owenkillew, Derg, Mourne Beg, Fairy Water, Strule, Owenreagh, Quiggery Water, Eskragh, Clough and Camowen.

3 - What is the name of the invasive organism

Response: *Oncorhynchus mykiss (Rainbow trout)*

4 – Is the organism known to be invasive elsewhere?

Response:
Since the late see 19th century rainbow trout have been widely stocked throughout North America and over time, in other locations across the world. Among the salmonids, rainbow trout have been introduced to all U.S. States outside their native range and to 87 countries worldwide, more than any other fish species. With the brook trout (*Salvelinus fontinalis* (Mitchill) and brown trout (*Salmo trutta* L.) they are the most widely introduced salmonids worldwide, and among the most widely introduced fishes. They have been introduced to 97, 49 and 42 countries, respectively, and are currently the third, 12th and 13th most widely introduced fish species. Due to multiple adverse effects, brown trout and rainbow trout rank

among the eight fish species included in the list of 100 of the world's most invasive alien species (Fausch, 2007).

Introduced diploid rainbow trout have extensively colonized New Zealand and parts of South America, as well as several locations in Europe. Self-sustaining populations have become established in all of these areas.

Crowl *et al* (1992) concludes that brown trout and rainbow trout have been the colonists of the fish world par excellence. They have been transported around the world and are now among the most widespread of species in cool fresh waters. Unfortunately, their introduction has often been detrimental to native fish populations and has often resulted in significant changes to the natural communities of the receiving waters. Species replacement and fragmentation in the native fish fauna are also of concern in New Zealand, and Australia, where brown and rainbow trout made early appearances.

Korsu *et al* (2010) has further shown that interactions among native and alien salmonids are highly context dependent, varying in relation to case specific factors such as characteristics of the species involved and the recipient environment. For example Closs (personal communication) points out that in New Zealand rainbow trout have a slightly higher optimum temperature preference / tolerance than brown trout and so out compete browns in warmer systems, hence their dominance on the North Island of New Zealand. In the cooler South Island the dominance in rivers switches to brown trout.

Introduced species may have an impact on native fish populations through competition, by predation and the introduction of alien diseases and parasites. Fausch (2007) has concluded that, if they became established, rainbow trout could potentially have negative effects on brown trout or Atlantic salmon (*Salmo salar*) in U.K. waters, but this probably depends on the context set by other factors.

5- What is an all-female triploid (AFT) rainbow trout?

Cells that are destined to become eggs in a female rainbow trout undergo a series of cell divisions called "meiosis". These special cell divisions lead to a reduction in the number of chromosomes in preparation for fertilization which restores a normal complement of chromosomes. Meiosis is not completed, however, until the eggs are fertilized. At the time of spawning, rainbow trout eggs have two sets of chromosomes. The second set of chromosomes is usually expelled from the nucleus to form a “barr body” (as in humans). If the eggs are subjected to pressure or heat shock for a short period of time this prevents the “barr body” from being expelled, by disrupting the small fibers that pull the chromosomes apart. The result is that each egg has two sets of chromosomes. Fertilization with a male sperm, which has one set of chromosomes, produces an egg with three sets of chromosomes. This means that triploid fish are unable to reproduce, because they cannot produce functional gametes. In many other ways they are similar to non-triploid or “diploid” specimens.

Solomon (2000) notes that many organs and tissues in triploids have larger but fewer cells, including the brain, muscle, retina, liver and kidney. This appears to arise because the extra set of chromosomes dictates an increase in cell nucleus dimensions which in turn affects overall cell size. The cells in triploid trout are larger because they contain 50% more DNA which might in theory cause problems such as reduced oxygen carrying capacity, due to the surface area to volume ratio of their red blood cells being lower than those of diploids. As a result, triploids may be more prone to stress (Chatterji *el al*, 2017 and Pawson, 2003). Pawson states that triploids are generally more sensitive to disease, but they do not suffer the post-spawning mortality seen in diploids. However, these rather fundamental differences appear to have remarkably little knock-on effect upon physiology, behaviour and general performance. Development rates appear very similar, until the onset of sexual maturity in diploids. Because of the absence of post-spawning mortality and their apparent resistance to fungal infections, AFTs are now preferred for both commercial aquaculture and stocking for recreation.

In terms of maturation there is a risk that some male triploids may still develop functional gonad tissue and may participate in spawning behaviour, which could interfere with reproduction of wild stocks. However, female triploids do not develop mature gonads and do not exhibit spawning behaviour (Solomon, 2003). This means that triploids do not reproduce. Importantly Solomon (2000) notes that triploids are not Genetically Modified Organisms (GMOs) in that there is no introduction of genetic material from other organisms.

6 - Are there conditions present in the Risk Assessment Area that would enable the organism to survive and reproduce?

Since the escapees present in the Mourne are all female triploids (AFT's) there is no risk that the rainbow trout will breed successfully. It might seem that the salmonid habitat would be ideal for rainbow trout but Fausch (2001 and 2007) has found that stocks of rainbow are particularly prone to damage from large flood events and that the flow regimes in the rivers of Northern Scotland and Ireland may be sufficiently harsh to prevent the recruitment of juvenile rainbow trout. This conclusion may have significance in relation to the over-wintering of the summerlings which formed a high proportion of the rainbow trout which escaped into the Mourne.

7- Has the organism established viable (reproducing) populations elsewhere?

As outlined above, rainbow trout have a long history of establishing viable populations of in suitable habitats. Frequently these successful colonisations are associated with stocking of juvenile rainbow trout from wild sources or from reared stocks which have established breeding populations. Given that the Mourne escapes are triploids, these colonisations are not directly comparable to the situation under consideration.

Non-native salmonids frequently escape from land-based fish culture facilities when they flood and from net pens when they break during storms, and both are under-reported and difficult to track (Fausch, 2001). There are no reported examples in Europe where recent mass escapes of rainbow trout have resulted in any long-term effects on local fisheries. However, none of the escapes were of the order of magnitude of the escape into the Mourne system and the majority of the escapes were adult trout. Recent significant rainbow trout escapes occurred from a marine trout farm in Denmark in 2016, comprising 80,000 escapes and two recent escapes in the UK: some 50,000 + from a rainbow trout farm on the River Exe in 2013 and a reported escape of 60,000 adult rainbow trout into the river Avon also in 2016.

8- What other impacts might be expected from a mass entry of AFT rainbows into a receiving water ?

While the use of all female triploids does greatly reduce the risk that stocks may become self -sustaining great care is required to ensure that as high a percentage as possible of the stocked fish are fully sterile. Although the use of sterile AFT's does all but eliminate the risk of creating self-sustaining stocks becoming established the stocking or the escape of very large numbers of AFTs does still poses significant other threats to the receiving waters.

When considering risks, ecologists often focus on single-factor explanations for invasions, whereas in many cases it is likely that various abiotic and biotic factors interact with each other, and with zoogeographic and evolutionary processes, to either hamper or foster the impacts arising from either stocking or accidental mass releases into river catchments.

In the case of the Mourne, such threats can be summarised as:

- Potential for triploids to compete for food with wild salmon and trout (both adult and
- juvenile);
- Potential for triploids to compete for space and displace wild salmon and trout;
- Potential for triploids to interfere with post spawning survival of wild salmon and trout stocks;
- Potential for increased predation by triploids on juvenile salmon and trout;
- Potential of triploids to introduce exotic parasites or diseases;
- Potential impacts of endemic parasites and diseases on the invading AFT stock;
- Potential for high densities of triploids to affect the overall biodiversity / ecological balance of the receiving waters and to cause fundamental shifts in riverine productivity.

The above are based on Noble *et al* 2004.

9 - What does the literature tell us about these impacts and how they might affect stocks of wild salmonids in the river Mourne and its tributaries?

A literature review and contacts with experts in the field provided surprisingly few studies on the impacts of rainbow trout AFT's on wild fisheries, particularly riverine systems. However, extensive research has been carried out on the effects of stocking with both diploid and AFT brown trout. Detailed work on the impacts of invasions of non-native rainbow trout have been carried out in North America, New Zealand and Japan. Studies on AFT brown trout and their inter-relationships with the resident wild trout most probably act as a surrogate for what may occur following the escape of rainbow trout AFT's into a wild salmonid system. However, as discussed in more detail in the conclusions section of this report, the escape into the Mourne is unprecedented in its scale and comprised a very high proportion of small summerling trout. These may well pose additional risks not present when the quoted studies were carried out on larger, 450g+, stocked, AFT brown trout.

Food

Walker (2004), showed that the diet of the stocked diploid rainbow trout he examined was varied and apparently fairly haphazard. Their stomachs contained a wide variety of invertebrates, terrestrial flies and beetles, but also fish pellets, anglers' baits and pieces of plant material, seeds, wood and stones. The stomach contents comprised primarily invertebrates, but there was a great deal of indigestible material, including sticks and stones. There was no evidence of predation on salmon or trout fry and parr and only one fish contained a single large minnow (75 mm).

Food items recorded in Walker (2004) included:

Chironomid pupae/adults
Terrestrial flies and beetles
Caddis larvae/pupae
Aquatic snails
Mayfly/stonefly larvae
Shrimp larvae
Water mites
Caterpillars
Fish (minnow)
Zooplankton
Fish pellets
Bait – worms, maggots, sweetcorn
Vegetable/woody debris
Stones

Chatterji *et al* 2007 found that the stocking of brown trout AFT's had no discernible impact on the numbers and volume of food items recorded in samples from wild trout. Generally, the three types of trout he examined (wild, stocked diploids and AFT's) consumed a similar composition of items. However, there were some differences and far more molluscs were recorded in the diet of the AFT's. The AFT's also showed a higher preference for terrestrial food than the mixed-sex diploid trout or the wild brown trout.

However, Fausch (2007) found that in reared rainbow trout, as a result of selection for high levels of aggression in the farm and for feeding on artificial foods, the stocked fish found the transition to natural foods difficult and this often resulted in starvation. Pawson (2003) showed stocked triploids (especially if they are larger than wild fish) can, nevertheless, compete directly with wild trout for limited food and habitat resources.

Baxter *et al* (2007) found that invading stream salmonids can differentially affect the availability of allochthonous (external to the river system) prey to the native fish, consequently altering the diet and reducing the growth and abundance of the native species. Recent investigations have shown that other similar effects are also possible, such as invaders that monopolize resources which are important to consumers in other neighbouring terrestrial habitats, dependent on the streams themselves.

Results from a comparative field study of six other stream sites corroborated these experimental findings. This work showed that at invaded sites, rainbow trout usurped the terrestrial prey subsidy to the streams, causing a more than 75% decrease in the biomass of terrestrial invertebrates in Dolly Varden (*Salvelinus malma*) diets and forcing them to shift their foraging to insects on the stream bottom. Habitat degradation and introductions of non-native species are two important human disturbances that may alter such prey subsidies. Evidence obtained from experiments on linked stream-forest ecosystems indicates that either type of disturbance can trigger complicated indirect effects in the recipient food webs, both in the streams and in biotopes dependent on the streams.

Density and Habitat Requirements

Chatterji *et al* (2017) report that following two consecutive years of stocking both diploid and triploid brown trout at a high level, there was no evidence to suggest that either had adversely affected the density, growth or biomass of wild brown trout of any of the age/size groups examined, nor was the condition or displacement of adult wild brown trout affected. Secondly, the relative performance of the two groups of stocked trout, in terms of growth and persistence, was assessed. Overall, the performance of stocked fish was poor. The highest rate of persistence (measured over the 2-5 months between stocking and electric fishing) was exhibited by the ATF brown trout in rich, lowland chalkstreams (15 per cent in 2005 and 30 per cent in 2006).

Walker (2004), when commenting on the issue of competition for space between wild brown trout and escaped rainbow trout, makes the point that clearly the escaped fish had been actively feeding and, by implication, finding living space, however temporary, that may have been originally occupied by native salmonids.

Preying on Eggs and Impacting Spawning of Wild Salmon and Trout

Solomon (2004) and Chatterji *el al* (2017) found that that brown trout AFTs continue to feed through the autumn while maturing diploid fish do not and this points to the possibility that triploids could predate on the eggs of spawning fish – certainly immature trout are known to do so. However, he asserts that in practice this has not been observed. AFTs remain in their natural territories and do not follow spawning fish onto the redds and despite considerable surveillance, no evidence of predation of wild brown trout eggs by stocked AFTs or all female diploids was recorded (Chatterji *et al*, 2017).

Noble *et al* (2004) and Pawson (2003) agree that there is no evidence that AFT's follow sexually maturing wild salmonids onto the spawning habitat. This would suggest that the use of all-female triploids does not poses a high risk and may even represent a reduction in risk from the use of diploids, especially if the habitat stocked is sufficiently spatially distinct from suitable spawning habitat. One of the reported concerns over triploid trout is that they continue to feed through the autumn whilst maturing diploid trout do not (Solomon, 2000), and therefore triploids may predate upon eggs of spawning fish. Whilst predation on eggs is known to occur in juvenile wild fish, there is little evidence to suggest a greater preponderance of this threat from triploid trout. Indeed, there is little evidence that cannibalistic predation on eggs by adult wild brown trout occurs or induces significant mortality.

Kitano (2004) found that, although non-native rainbow trout fed prey primarily on aquatic and terrestrial invertebrates, eggs and larvae of the native river sculpin (*Cottus nozawae*) constituted 10% of their diet in Horonai Creek, Hokkaido, Japan. They also actively preyed on the eggs and fry of chum salmon (*Oncorhynchus keta*), the fry of masu salmon (*O. masou*) and, on rare occasions, voles in streams. That established populations of non-native rainbow trout actively selected terrestrial prey over aquatic prey, because of the larger size of the terrestrial prey and their peak flux into streams during the evening. Consequently, rainbow trout consumed 77% of the total input of terrestrial prey into a stream reach during mid-summer, and this constituted 73% of their daily ration.

Fausch and Closs (personal communication) confirm that in the wild a variety of salmonids in North America often eat Pacific salmon eggs, but they are usually surplus eggs that are displaced out of the redds without being buried. He also suggested that even if escaped rainbow trout were in the vicinity of spawning wild salmonids (brown / sea trout and salmon), the wild males would, as best they could, keep the rainbow trout well away from the spawning area. Their success would of course be dependent on the density of rainbow trout attempting to eat the freshly laid eggs.

Post-Spawning Survival / Overwintering

Chatterji *et al* (2017) and Pawson (2003) found that AFT brown trout do not migrate to spawning grounds and display no clear migratory movements around spawning time. Both authors failed to find any records of AFTs producing viable eggs, nor was there any record of AFTs displaying spawning behaviour. AFTs are, therefore, unlikely to disrupt the normal spawning behaviour of wild salmon and trout.

It seems that overwintering survival of AFT brown trout is higher when compared with farmed diploid trout and as a result they have a wider window for competition with wild fish. The appearance of the over wintered AFTs is also distinctly different from fish which have undergone sexual maturation and reflects their non-mature status. While the evidence clearly indicates a generally low persistence and probably poor survival of both stocked diploids and AFTs, particularly in the upland rivers, a higher proportion survives compared to diploid brown trout. This could reduce wild trout recruitment due to their locking up resources without contributing to the population (Chatterji *et al*, 2017 and Solomon, 2000).

In discussing the growth rates of reared AFT brown trout Noble *et al* (2004) outline that on average the growth of triploids is not as rapid as diploids, and therefore they attain a smaller size at the end of their first year (400g compared with 450g – 500g for diploids). However, by the end of the second year triploids are frequently larger than diploids of the same age, as the majority of the diploids will have entered maturity and have diverted energy to gonadic growth. Early in the third year the triploids may be up to 4-7 months more advanced in growth than diploids which are still recovering from a spawning cycle.

Stocked fish that have not participated in spawning will therefore be in better condition than recovering wild stock; this, linked with higher levels of aggression, may therefore result in a higher competitive ability compared with recovering wild fish. In a situation where resources are limiting, this competitive superiority may affect the survival of post-spawners. Solomon (2003) suggests that triploids stocked under in the autumn exhibit good growth and survival over winter and are more active and in better condition than wild fish at the start of the following fishing season. This may confer on triploids a competitive advantage over recovering wild fish. Whether this will negatively affect the recovery and survival of wild fish is likely to depend upon whether resources are limiting, which may well be the case in poorer upland systems such as the Mourne catchment.

Predation by Triploids

Another concern, often expressed following the mass escape of reared fish, particularly rainbow trout, is the risk that they will prey heavily on the juveniles of wild salmon and trout. Walker (2004) found this to be a major concern of anglers and also stated that, over the years, the FRS Freshwater Laboratory in Scotland had received a number of anecdotal accounts from the Rivers Earn, Tay and Aray (Argyllshire) of rainbow trout eating salmon fry and parr. However, he found that densities of salmon and trout fry and parr appeared to be normal at sites close to the rainbow trout farms in Scotland, suggesting that predation by escaped rainbow trout is insignificant. Importantly he found, as outlined earlier, that fish comprised a negligible component of the diet of the escaped rainbow trout. Chatterji *et al* (2017) also found no evidence to suggest that heavy predation on wild fish by either stocked diploids or AFTs had taken place during the summer in the rivers he studied. He further noted that fish remains were recorded more frequently in samples from wild trout, when compared to the two types of stocked trout. When the stomach samples from the three types of trout (wild, diploid and AFTs) were analysed for fish remains, bullheads (*Cottus gobio*) were the most common by number forming 57 and 41 per cent of all fish recorded in samples from upland and lowland river sites respectively. Very little evidence was found of predation by stocked fish on juvenile wild brown trout. Shields (2007) also found that triploids contained significantly less fish in their diet than wild trout. The one exception would appear to be large, naturalized, stocked brown trout which do appear to prey on wild salmonid juveniles. They have a catholic diet but overall make up a relatively small proportion of their diet (Noble *et al* 2004).

Introduced exotic rainbow trout in Japanese streams have been implicated in reducing populations of native fishes, especially stream salmonids, through predation, competitive interaction for resources, and interspecific hybridization (Kitano, 2004). Baxter *et al* (2007) also found that at most of the sites where introduced rainbow trout were present in his study he found few age-0 or juvenile Dolly Varden (*Salvelinus malma*). Rainbow trout may also have reduced the numbers of Dolly Varden indirectly by preying on 0 group native charr .

There is evidence that triploids continue to actively feed into the autumn and over winter, when diploids stop feeding and start to mature ready for spawning (Solomon, 2000).There is a risk that as rainbow trout continue to forage and become habituated to feeding on natural food sources, and as the abundance of juvenile alevins and fry increases in spring, fish may become, for a period at least, a larger proportion of the rainbow trout diet.

Parasites and Diseases

One of the main risks of fish farm escapes / stocking is the potential hazards of the accidental introduction of alien diseases and parasites, or increased prevalence of disease caused by stocking fish with elevated pathogen loadings (Noble *et al* 2004). Stocking of hatchery rainbow trout in rivers has led to the introduction of whirling disease into open waters in some parts of the United States. Whirling disease (*Myxobolus cerebralis*) is a trout and salmon parasite discovered in 1893 when rainbow trout were imported into Germany and contracted the disease. Although not present in Ireland, it is found throughout several other European countries. Its rapid spread once introduced and the difficulties encountered in controlling the disease, emphasises the need for the tightest possible biosecurity when rearing facilities are situated in the catchment area of wild salmonid waters.

Wild brown trout and Atlantic salmon are highly susceptible to fungal infections such as *Saprolegnia*, especially larger fish. Such infections are associated with the onset of maturation or the rigors of spawning. Cultured trout can also be subject to high over-winter mortality caused by these secondary infections. However, AFTs are far less susceptible and triploids suffer far lower winter mortality from secondary fungal infections than farmed diploids (Solomon, 2000 and Noble, 2004).

In spring of 2017 the author was investigating outbreaks of *Saprolegnia* in stocks of post-spawning salmon and sea trout from several fisheries in Scotland and Ireland. He received reports that in April, in Lough Lene, Co Westmeath, large numbers of post-spawning pike died as a result of a *Saprolegnia* infection. A significant number of rainbow trout AFTs overwinter in Lough Lene for two to three years post stocking and at the time, the lake held a good stock of large, over-wintered AFT rainbow trout. However, not a single AFT was recorded displaying symptoms of the fungus.

Noble *et al* (2004) suggest that whilst there has been no study of the parasite tolerances of diploid and triploid brown trout, it is an issue that may need consideration, given the apparent differences in resistance to diseases. Furthermore, if triploids exhibit higher susceptibility and lower tolerance to certain diseases it could influence their performance when stocked and exposed to wild conditions. Equally AFTs which are naïve to wild parasites and latent, low grade diseases, may well find it more difficult to survive in an alien wild environment.

Biodiversity and Ecological Balance in the System

In describing the potential for rainbow trout to invade streams in the UK, Fausch (2007), outlined that introduced species, once established can have direct and indirect effects on entire aquatic food webs (e.g. invertebrates and algae) that cascade throughout ecosystems, or even cross boundaries into adjacent ecosystems . Such changes can manifest themselves at all levels of ecological organisation. For example, invading rainbow trout may alter the behaviour, abundance or distribution of a native fish (direct effects at the individual and population level), which in turn may reduce predation pressure on zooplankton or benthic invertebrates that graze algae and alter carbon and nutrient dynamics (indirect effects at the community and ecosystem level). Rainbow trout can also have strong indirect effects on food webs in both streams and lakes, which can alter ecosystem processes and even cascade across boundaries into adjacent ecosystems. Thus, non-native rainbow trout potentially have strong direct and indirect effects that affect not only other salmonids, but also entire stream and lake communities, and even riparian predators like birds, bats, lizards and spiders.

Baxter *et al* (2004 and 2007) carried out large-scale field experiments in northern Japan which showed that that invasion by non-native rainbow trout interrupted reciprocal flows of invertebrate prey that drove stream and adjacent riparian forest food webs. As noted above, rainbow trout usurped terrestrial prey that fell into the stream, causing native Dolly Varden (*Salvelinus malma*) to shift their foraging to insects that graze algae from the stream bottom. These field experiments, clearly demonstrated that a non-native fish caused strong indirect effects that not only cascaded down to the base of the aquatic food web to increase stream algae, but as outlined by Fausch (2007), also extended across the terrestrial– aquatic boundary via emerging insects to depress riparian spider abundance. Thus, by simply modifying the foraging behaviour of a native salmonid, non-native rainbow trout caused a trophic cascade in the stream community that reduced emerging adult insects and, in turn, reduced the density of forest consumers. Consequently, Baxter *el al* (2004) concluded that human disturbances such as species introductions or habitat destruction that alter these reciprocal food web subsidies may change either or both systems

Korsu *et al* 2010 outline the enemy release hypothesis, where alien species benefit from having left their old enemies (predators, competitors and parasites) behind, while native species continue to struggle against their co-evolved natural enemies. This may give the invaders at least temporary advantage. It thus appears that interactions among native and alien salmonids are highly context-dependent, varying in relation to case specific factors such as characteristics of the species involved and the recipient environment. Despite considerable context-dependency, analyses provided by Korsu *el at* (2010) provide some evidence for general patterns in salmonid invasions. Adverse effects were detected for both individual- and population-level variables, potentially, over the longer-term as alien populations became established, driving native fish to the brink of extinction. An important implication from this study was that introductions of alien salmonids beyond their natural ranges almost certainly incur a high risk of negative impacts on native biota (Kitano, 2004).

The establishment of non-native salmonids can be limited by abiotic factors such as flow and temperature regimes, and biotic resistance from competition, predation and parasites or diseases, which often most strongly affect early life stages. Fausch *et al* (2001) predicted that flow regimes in regions where rainbow trout invasions are successful would match those in their native range and would differ from those in regions where invasions are moderately successful or failed. Invasions are most successful in a region with a flooding regime most similar to that in their native range on the Pacific Coast of North America (i.e. winter floods and summer low flows), and are unsuccessful in regions with a harsh summer flooding regime (Fausch, 2007). It is therefore clear that a difference in timing of the flooding regime among regions has a strong influence on rainbow trout recruitment and therefore invasion success.

Having examined thermal and hydrological regimes in the UK, Fausch (2007), concluded that even in the coldest winters stream temperatures were unlikely to limit the spread of rainbow trout recruitment and prevent the spread of the species in the British Isles. He also pointed out that stream temperatures in the region are rising as climate change takes hold. However his analysis did support the conclusion that flow regimes in some rivers in the north of the UK are sufficiently flashy, and summer floods are frequent enough, to displace rainbow trout juveniles and limit their establishment. Moreover, the frequency and magnitude of floods in the region he examined, which included the Mourne catchment, have increased, and are projected to increase further with climate change.

The above studies relate to invasions by diploid rainbow trout. However aspects of mass invasions by domesticated rainbow trout may, at least in the short to medium term, mimic the main aspects of diploid rainbow trout invasions outlined above. It is highly likely that the introduction of large numbers of escaped rainbow trout will cause a loss in productivity of the individual wild fish species (Walker, 2004). Pawson (2003) concludes that stocking or invasion by brown trout AFTs may, through aggressive behaviour, result in the displacement of wild trout from their preferred habitat; energetic costs may increase for wild trout with a reduction in growth and reproductive capacity, due to territory defence and competition for food; modification (destruction or deprivation) of habitat or feeding resources used by wild trout may occur; the invaders may host non-native or exotic diseases, and there may be ramifications for recruitment success in wild trout through competition for food or predation.

In the case of stocked adult brown trout AFTs, Chatterji *et al* (2017), concluded there was no evidence of impacts on the growth, abundance and diet of wild brown trout in the rivers surveyed. However, Noble *et al* (2004) pointed out that, when released into the wild, hatchery-reared fish are generally more aggressive than wild fish and engage in more (and often longer) aggressive interactions.

This can result in potential impacts from stocked fish on wild fish community structure and ecosystem dynamics. Stocked fish have the capability of disrupting ecosystem dynamics by altering the functioning of the system. Stocked trout can potentially disrupt food webs, especially if they predate on key stages in the food chain. Indeed rainbow trout are now being used in bio-manipulation experiments to control zooplanktivorous fishes in eutrophic lakes. It is possible therefore, that selective foraging may disrupt the food web and lead to more subtle, indirect changes in wild trout populations.

As concluded by Fausch (2007), when reviewing the potential limiting factors on the establishment of self-sustaining rainbow trout stocks in the UK, hydrological aspects of each catchment, particularly flows rates, may be a major determinant of success or failure. There is also strong evidence that the behaviour of stocked brown trout, particularly AFTs may be strongly influenced by flow rates. Solomon (2000) suggests that if a river is over-stocked with triploids, they are displaced downstream, not the wild fish. Also Chatterji *et al* (2017) and Pawson (2003) found that there was no upstream movement recorded amongst the all-female triploid group. Both the all-female diploid and all-female triploid groups were more easily displaced downstream during high water flows and over time, showed a distinct downstream movement.

10 - Could the organism cause serious economic or social harm in the Risk Assessment Area?

Since escaping into the River Mourne in late August 2017, the AFT rainbow trout have caused very serious impacts to the wild salmonid game fisheries downstream and immediately upstream of the trout farm. Low level leakage of rainbow trout from the two rainbow trout farms in the catchment and two previous larger scale escapes, one from each farm in 2XXX and 2XXX (Loughs Agency to provide dates), has resulted in anglers encountering rainbow trout as a constant by-catch while fishing for salmon or trout downstream of both farms. However, the mass escape of this past summer was unprecedented in its scale and magnitude and largely brought to a premature close salmon fishing on several key salmon fisheries immediately downstream of the farm.

As a result some eight key weeks of the prime salmon angling season were lost, as anglers could not fish effectively for salmon given the high concentrations of rainbow trout packed into the pools. Brown trout fishing in the river was practically impossible, as rainbow trout escapees were densely packed into the fishing pools and grabbing at any trout fly, lure or bait used by anglers. This loss of angling resulted in significant economic losses to proprietors, angling clubs and business associated with angling on the river (accommodation, tackle shops, angling guides, grocery stores etc). It was also socially disruptive to an area where a very significant number of residents are dependent on traditional angling as a source of relaxation and enjoyment.

Walker (2204) outlines the legal consequences of a similar large scale escape of rainbow trout in England, in the early 90's. A case was taken by the Savernake Fly Fishing Club against a local fish farmer for damage caused by the negligent escape of rainbow trout into their prime brown trout fishery. The club won its case and a very significant fine was levied by the court for loss of amenity and enjoyment. Damages were based on a proportion of the total annual value of annual fishing membership charges in the most affected year, plus an amenity factor of 50% representing loss of enjoyment.

As outlined previously AFT brown trout survive well over winter and are very free-rising early in the season, having fed all winter long (Noble *et al* 2004). If the escaped rainbow trout behave in the same manner and if significant numbers of trout over-winter in the prime salmon and trout pools, the rainbow trout escape of August 2017 could continue to have serious consequences for fishing for both salmon and trout during 2018 and result in additional losses to the local economy and to the enjoyment of a highly prized sporting resource, of local and national importance (Dillon *et al*, 2000).

It has been suggested that some of the escaped AFT rainbow trout might migrate to sea and return as "steelhead" (the migratory form of rainbow trout), further complicating the effects of the mass escape. Research carried out by the author in both New Zealand and Chile indicates that while the now resident rainbow trout in these two countries do at times visit the upper estuaries of rivers, there are, to date, no confirmed runs of migratory steelhead rainbow trout. Research carried out by Cotter *et al* (2000 and 2002) on triploid salmon clearly showed a lower return rate of adults to the coast and to fresh water. It therefore seems unlikely that significant numbers of the escaped AFT rainbow will adopt a migratory marine life style.

Summary Overall Risk Assessment

Estimate the overall likelihood of entry into the Risk Assessment Area for this organism.

Response: ~~*very unlikely | unlikely | moderately likely | likely |*~~ *very likely/* ***certain***
Confidence: ~~*very low | low | medium |*~~ *high* | ~~*very high*~~ */* ***certain***

Comments: The organism is already present in the River Mourne catchment as a result of the mass escape from the trout farm in August 2017, previous escapes from the two rainbow trout farms in the catchment and the leakage of small numbers of trout into the river since the farms were established.

Establishment Summary

Estimate the overall likelihood of establishment.

Response: ***very unlikely*** | ~~*unlikely | moderately likely | likely | very likely*~~
Confidence: ~~*very low | low |*~~ ~~*medium*~~ | ~~*high*~~ | ***very high***

Comments: Since the escapees are AFT rainbow trout, it is most unlikely that even if some diploid male and female fish are present that a population of trout will become established. Previous escapes and the loss of small numbers of trout from the farms over time has not resulted in the establishment of the species in the catchment.

Spread Summary

Estimate overall potential for spread.

Overall response: ~~*very slow | slow*~~ | ~~*intermediate*~~ | ***rapid*** | ~~*very rapid*~~
Confidence: ~~*very low | low | medium*~~ | ***high*** | ~~*very high*~~

Comments: It is most likely that the spread will be largely confined to a downstream movement of fish but, since the escape in August, some upstream movement has already been recorded. It is important that this feature of the escape is closely monitored and where possible at least semi-quantified.

Sub scores:

Natural spread only:
Response: ~~*very slow | slow*~~ | ~~*intermediate*~~ | ***rapid*** | ~~*very rapid*~~
Confidence**:** ~~*very low | low | medium*~~ | ***high*** | ~~*very high*~~

Human facilitated spread only:
Response: ***very slow*** | ~~*slow | intermediate | rapid | very rapid*~~
Confidence**:** ~~*very low | low | medium*~~ | ***high*** | ~~*very high*~~

Impact Summary

Estimate overall severity of impact

Overall response: ~~*minimal | minor | moderate*~~ | ***major*** | ~~*massive*~~
Confidence: ~~*very low | low | medium*~~ | ***high*** | ~~*very high*~~

Comments: These scores are based on a judgment that the overall impacts will be limited to one or at most two more years - 2018 and 2019 and that steps are taken to ensure that no further significant escapes of AFT rainbow trout occur over that time.

Sub-scores:

Environmental Impacts:
Response: ~~*minimal | minor | moderate*~~ | ***major*** | ~~*massive*~~
Confidence: ~~*very low*~~ | ~~*low | medium | high*~~ | ***very high***

Economic Impacts:
Response: ~~*minimal | minor | moderate*~~ | ***major*** | ~~*massive*~~
Confidence: ~~*very low | low | medium*~~ | ***high*** | ~~*very high*~~

Social Impacts:
Response: ~~*minimal | minor*~~ | ***moderate*** | ~~*major | massive*~~
Confidence: ~~*very low | low |medium*~~ | ***high*** | ~~*very high*~~

Comments: Again, these responses are based on the assumption that the impacts will be confined largely to 2017 and 2018, with a risk that they will continue until 2019. There is also an assumption that the AFTs will not move upstream to the main spawning tributaries but that the impacts of the escapees, although severe in the short to medium term, will be largely confined to the main stem of the River Mourne. The short term environmental impact on the areas of the main river affected have the potential to have a short lived, major environmental impact on the overall ecology of the areas of the river affected. Equally, the economic impacts have already proven very significant and if they carry through to 2018 could prove a major blow to the economic and social benefits arising from the fishery.

Climate Change

What is the likelihood that the risk posed by this species will increase as a result of climate change?

Response: ***very low*** ~~*| low | medium | high | very high*~~
Confidence: ~~*very low | low | medium | high*~~ | ***very high***

Comments: The time scale involving any impacts resulting from this source, unless there are further major escapes of rainbow trout into the system, are too short to be affected by future climate change effects on the catchment, which are likely to take place on a decadal scale.

CONCLUSION

Estimate of the overall risk.

Response: ~~*very low | low | medium*~~ | ***high*** | ~~*very high*~~
Confidence: ~~*very low | low | medium*~~ | ***high*** | ~~*very high*~~

Comments: Overall conclusion is based on the assumptions outlined above regarding the location of the likely impacts in the catchment and the time scale involved.

A summary of the overall risks:

1. Potential for triploids to compete with wild salmon and trout for food (both adult and juvenile)

It is likely that the high proportion of summerling rainbows currently in the river will lead to intense competition for food with wild juvenile salmon and trout in the areas where high densities of the smaller rainbow trout are located. This increased level of competition could have an impact on the wild stocks of fish in the system. It should also be noted that due to increased predation from both birds and mammals, high flows and lack of suitable food, many of the larger, 1+ rainbow trout may die over winter.

2. Potential for triploids to interfere with post spawning survival of wild salmonid stocks

There is a significant risk that the juvenile AFT rainbow trout may indirectly affect post-spawning survival of wild trout (brown and sea trout) and salmon through competition for space and food. It is very unlikely they will have any effect on recovering salmon kelts.

3. Potential for triploids to compete for space and displace wild salmonids

There is a significant risk that the juvenile AFT rainbow trout may gain an advantage over the winter period and compete directly with juvenile salmon and trout, and recovering adult wild trout, for river bed habitat at least in the short term. A positive result could be that the rainbows may provide an additional food source for the larger, adult resident wild trout and to the small head of pike in the system.

4. Potential for increased predation by triploids on juvenile salmonids

It is possible to envisage a situation where large numbers of actively feeding / scavenging juvenile rainbow trout could feed for a short period on alevins and emerging fry. This could take place in redding areas of the main channel and in the lower pools of tributaries flowing into the main stem. The relative importance of the contribution made by main stem spawning to overall salmon production in the Mourne system is unknown. However, given the rocky nature of the river bed in the main channel and the extensive records of salmon spawning in the upper tributaries, it is unlikely that predation on alevins and fry in spring is likely to affect overall salmon production. It may affect trout production in the main stem where wild trout spawning is more likely to take place.

5. Potential of triploids to introduce exotic parasites or diseases

Given the disease free health status of the rainbow trout when they entered the system it is most unlikely that there is any potential for the escapees to introduce exotic diseases or parasites to wild fish in system. The AFT rainbow trout may well display a greater ability to deal with fungal infections such as *Saprolegnia* and this may provide them with a distinct advantage over the winter and early spring periods. One potential beneficial effect from the increased numbers of rainbow trout in the Mourne is that they may act as additional hosts for the freshwater pearl mussel, *Margaritifera margaritifera* (Beasley and Roberts, 1996). Kitano *et al* (1993) give an example from their studies in Japan of the parasitic larvae of another endangered freshwater mussel (*Margaritifera laevis*), which utilized invasive brook trout as hosts instead of scarce native white-spotted char.

6. Potential impacts of endemic parasites and diseases on the invading AFT stock

AFT rainbow trout may be adversely affected by native fish parasites such as cestodes (tapeworms) and nematodes (roundworms), which are common in the gut of wild salmonids living in the Mourne catchment (Kennedy, 1974). If their immunity to such parasites is low this may increase mortality amongst the AFT rainbows, particularly as the fish increase in size and feed more extensively on snails and crustacea, which often act as the hosts to such parasites.

Management Options and Recommendations

Response:

1. List the available pathway management options (to reduce spread) for this organism and indicate their efficacy.

Following the mass escape, the Loughs Agency tested a range of removal methods including electrical fishing, fyke netting and traditional angling. Given the scale of the escape from the trout farm none of these methods proved successful in significantly reducing the numbers of escaped rainbows. Over the course of the angling season, which ended on the 20th October 2017, anglers have, on a voluntary basis, put in a very determined effort to remove as many escaped trout as possible from the main stem of the river. Using sweet corn and worms anglers have reported on social media catches of up to 360 in four angling sessions, with a catch rate of one rainbow trout every 2 minutes. It was also noted that because of the small size of many of the rainbows encountered and the ease with which the fish could be caught, anglers found fishing for them boring and it was difficult to remain motivated, even though the anglers appreciated the need to remove the fish from the river. Overall the number of trout removed from the system by angling was probably modest but important none the less. Angling returns have proven very useful in providing valuable information on the location and spread of the escapees. Traditional angling methods have been used elsewhere in the UK to remove a significant number of escaped rainbow trout (Mike Holland, Richard Battersby and Philip Rudd personal communication) but in these cases the extent of the escape was far smaller and the size of the fish were significantly bigger, as they were trout intended for stocking. Despite the size of the trout and the quality of the fish, which were in prime condition, they proved an easy quarry and again anglers became demotivated after a few visits.

One possible option to help with the removal of some of the escapees over the winter period is to re-open the river to angling, with a view to encouraging anglers to remove a proportion of the rainbow trout. Experience elsewhere has shown that controlling angling on a river during the close season results in all sorts of difficulties relating to access, spawning area disturbance and the accidental by-catch of native fish. Given the size of the river involved, the time of year and the number of escapees present, it is probably not feasible to remove significant numbers of fish by angling or indeed by any of the other methods open to the Loughs Agency.

While impacts on the river at and below the point of entry of the escaped fish are likely to be significant, the numbers of rainbow trout reaching the key spawning areas in the upper tributaries are likely to be small. The impacts on salmon spawning areas in the upper reaches are therefore likely to be insignificant. However, given the vital importance of these areas, they should, where possible, be monitored using traditional methods such as spot electrical fishing and surveys for rainbow trout on a presence or absence basis. Where this is not feasible, the rapid-catch, coarse angling techniques described below should be used.

Whelan (1983) used coarse angling techniques over a seven-year period to assess and quantify the abundance and location of bream (*Abramis brama*) shoals in the River Suck, Cos Roscommon / Galway. It is recommended that this approach is used to assess the spread and location of the AFTs in the system and also to semi-quantify quantify the numbers of fish present in key locations over time. The exact details for such an approach will need to be agreed with management and staff of the Loughs Agency over the coming weeks.

2 - List the available control / eradication options for this organism and indicate their efficacy.

Response:
Given the nature and size of the Mourne catchment and the unprecedented numbers of rainbow trout present in the system, there are no effective control or eradication methods which can be used to physically remove a significant number of the fish from the catchment. However, the key spawning areas should be closely monitored and should these become infested with rainbow trout, every effort should be made to remove these as quickly as possible from the key salmon spawning areas. Again, it would appear that the only methods available to achieve this goal are electrical fishing and rapid-catch coarse angling techniques.

3- How quickly would management need to be implemented in order to work?

Response:

To assess the presence or absence of escapees in the main salmon spawning tributaries, to obtain an estimate of the concentrations of rainbow trout present and to ensure that they have not occupied key spawning areas, a comprehensive programme of assessment would need to be drawn up and implemented by late November.

4 – Short to Medium-term Monitoring and Semi-quantitative / Quantitative Assessment of the invading AFTs

Response:

- Collate and analyse all relevant information since the escape: e- fishing records, netting records, rod catch records, rod catch rates, fish locations, stomach contents, age/ length data, condition factors, presence of viable gonads in larger fish and if possible a measure of visceral fat content.
- Compile a stratified field sampling programme, based on the rapid-angling technique, to assess over time, the distribution and abundance of the remaining escapees in selected sites along the main stem and in some of the key spawning tributaries. Such a programme will obviously be resource limited and will also depend on the availability of 6 to 8 skilled volunteer coarse anglers, but ideally should be carried out under supervision of Loughs Agency staff, once in November and December, 2017 and again in February and April, 2018. Based on estimates of over-wintering survival and the feeding patterns /location of the residue stock of rainbows, a decision can be made whether or not to continue sampling over the remainder of 2018 and the frequency / type of sampling required.
- Even though it will not be possible to analyse all of the scientific information collected in real time, the valuable biological records and material collected during the winter / spring surveys should be fully analysed at a later date. To facilitate this, the data could be used to support a number of undergraduate or post-graduate student projects.
- When sampling, particular care should be taken to separate out naturalised rainbows, arising as a result of previous low-level escapes, and the rainbows from the most recent escape. In this way, it may be possible to get some idea of the base stock of rainbows which was present in the river before the mass escape of August 2017.

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Hyperlinks:

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https://link.springer.com/article/10.1007/BF00045038 - The impact of introduced brown and rainbow trout on native fish: the case of Australasia

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This is like shooting fish in a barrel! Anglers left downcast as river teems with 60,000 trout... making their hobby 'too easy'

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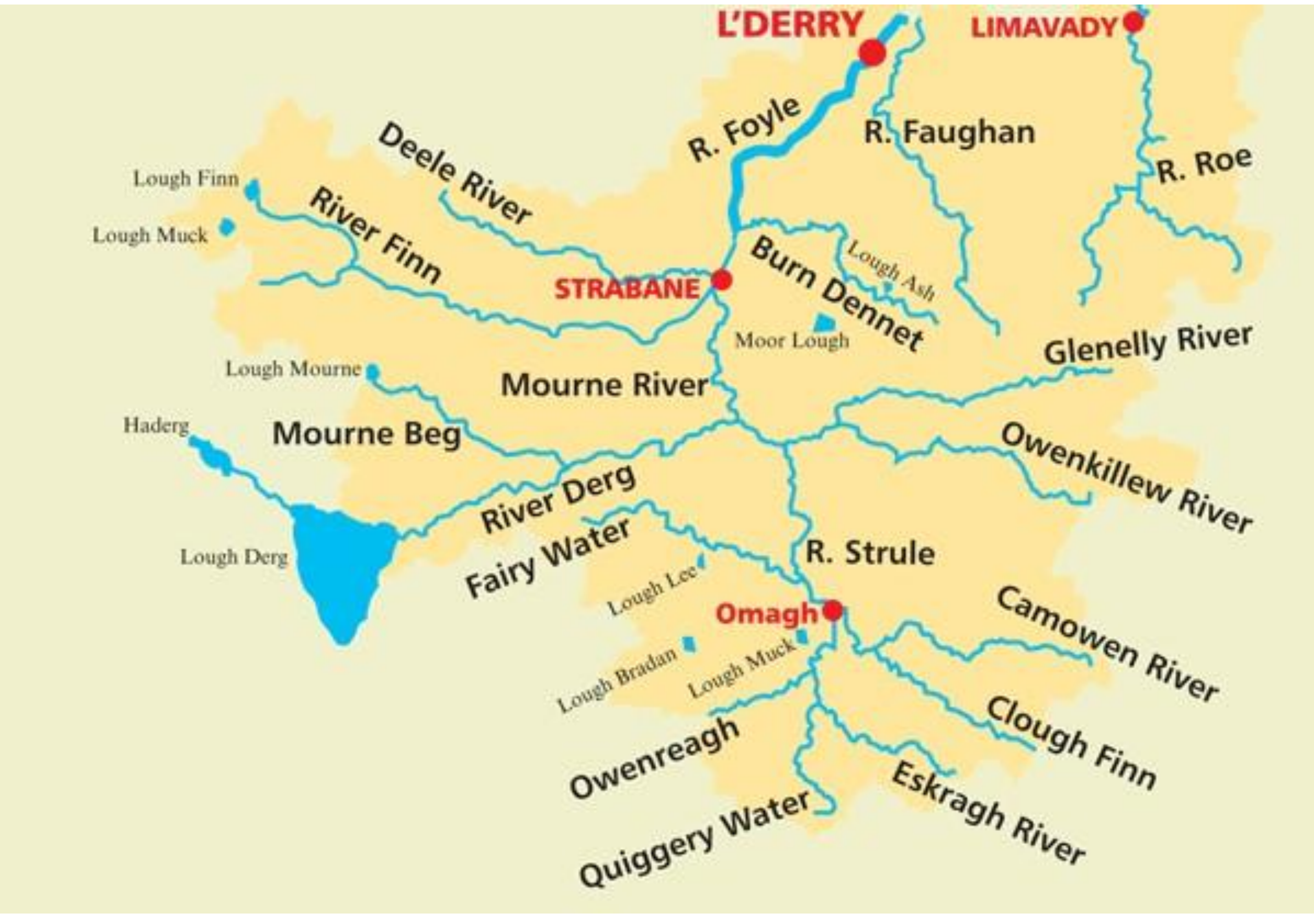
Appendix 1

River Mourne and Tributaries



Appendix 2

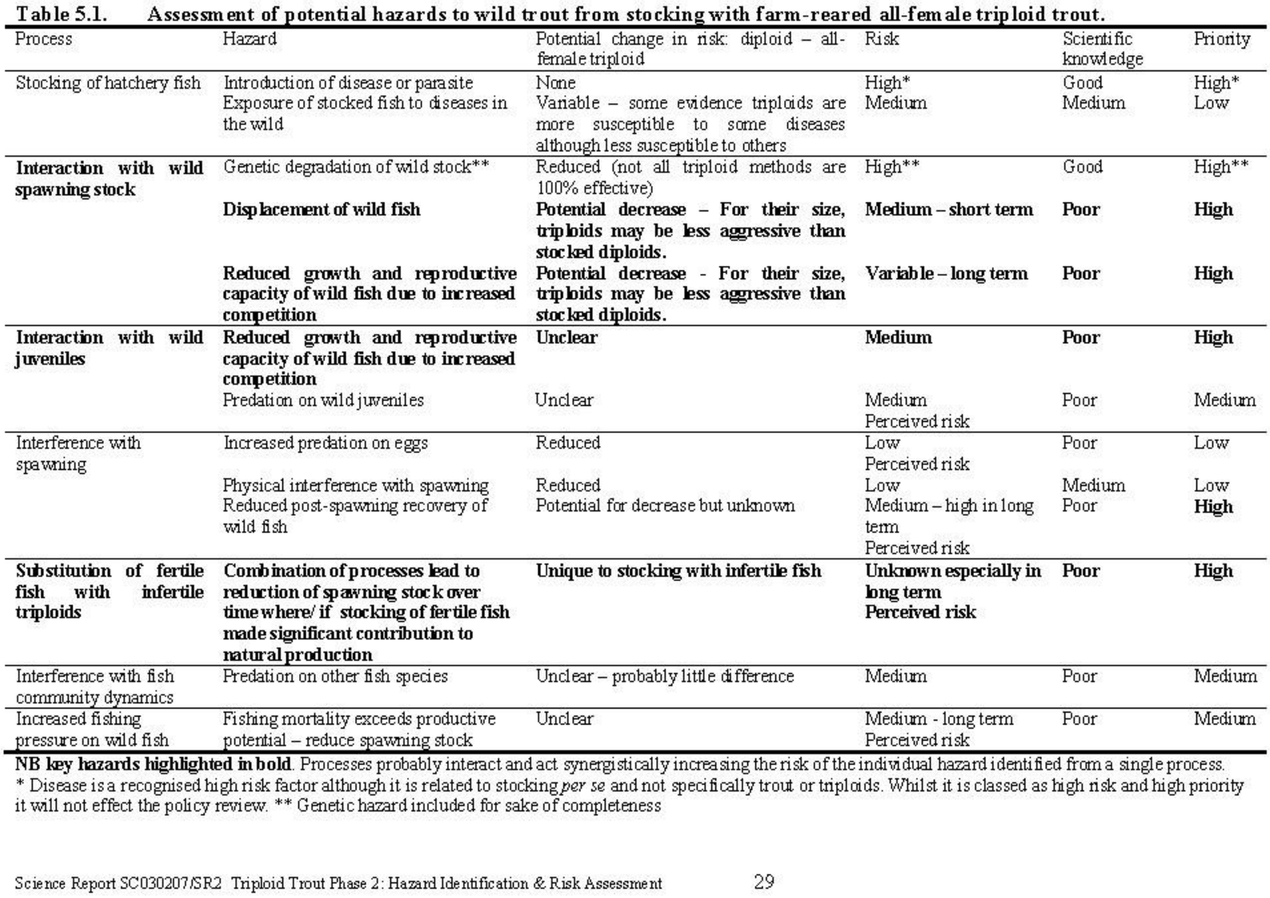


Table 5.1. Assessment of potential hazards to wild trout from stocking with farm-reared all-female triploid trout.

Process	Hazard	Potential change in risk: diploid – all-female triploid	Risk	Scientific knowledge	Priority
Stocking of hatchery fish	Introduction of disease or parasite	None	High*	Good	High*
	Exposure of stocked fish to diseases in the wild	Variable – some evidence triploids are more susceptible to some diseases although less susceptible to others	Medium	Medium	Low
Interaction with wild spawning stock	Genetic degradation of wild stock**	Reduced (not all triploid methods are 100% effective)	High**	Good	High**
	Displacement of wild fish	**Potential decrease – For their size, triploids may be less aggressive than stocked diploids.**	**Medium – short term**	**Poor**	**High**
	Reduced growth and reproductive capacity of wild fish due to increased competition	**Potential decrease - For their size, triploids may be less aggressive than stocked diploids.**	**Variable – long term**	**Poor**	**High**
Interaction with wild juveniles	**Reduced growth and reproductive capacity of wild fish due to increased competition**	**Unclear**	**Medium**	**Poor**	**High**
	Predation on wild juveniles	Unclear	Medium Perceived risk	Poor	Medium
Interference with spawning	Increased predation on eggs	Reduced	Low Perceived risk	Poor	Low
	Physical interference with spawning	Reduced	Low	Medium	Low
	Reduced post-spawning recovery of wild fish	Potential for decrease but unknown	Medium – high in long term Perceived risk	Poor	**High**
Substitution of fertile fish with infertile triploids	**Combination of processes lead to reduction of spawning stock over time where/ if stocking of fertile fish made significant contribution to natural production**	**Unique to stocking with infertile fish**	**Unknown especially in long term** **Perceived risk**	**Poor**	**High**
Interference with fish community dynamics	Predation on other fish species	Unclear – probably little difference	Medium	Poor	Medium
Increased fishing pressure on wild fish	Fishing mortality exceeds productive potential – reduce spawning stock	Unclear	Medium - long term Perceived risk	Poor	Medium

NB key hazards highlighted in bold. Processes probably interact and act synergistically increasing the risk of the individual hazard identified from a single process.
* Disease is a recognised high risk factor although it is related to stocking *per se* and not specifically trout or triploids. Whilst it is classed as high risk and high priority it will not effect the policy review. ** Genetic hazard included for sake of completeness

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From Noble *et al* 2004