GB Non-native Species Rapid Risk Assessment (NRRA)

Rapid Risk Assessment of: *Oncorhynchus gorbuscha* (Walbaum) (pink or humpback salmon)
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Introduction:
The rapid risk assessment is used to assess invasive non-native species more rapidly than the larger GB Non-native Risk Assessment. The principles remain the same, relying on scientific knowledge of the species, expert judgement and peer review. For some species, the rapid assessment alone will be sufficient, others may go on to be assessed under the larger scheme if requested by the Non-native Species Programme Board.

Guidance notes:

- We recommend that you read all of the questions in this document before starting to complete the assessment.
- Short answers, including one-word answers, are acceptable for the first 10 questions. More detail should be provided under the subsequent questions on entry, establishment, spread, impacts and climate change.
- References to scientific literature, grey literature and personal observations are required where possible throughout.

1 - What is the principal reason for performing the Risk Assessment? (Include any other reasons as comments)

Response: To assess the risk associated with this species in GB in response to a request via Defra from various English and Scottish government departments/agencies.

2 - What is the Risk Assessment Area?

Response: Great Britain (England, Scotland, Wales and their islands)

3 - What is the name of the organism (scientific and accepted common; include common synonyms and notes on taxonomic complexity if relevant)?

Response: *Oncorhynchus gorbuscha* (pink or humpback salmon)

4 - Is the organism known to be invasive anywhere in the world?

Response: Yes, see Figure 1. Fuller *et al.* (2015) states that established non-native populations, existing entirely in freshwater, are present throughout the Great Lakes. Fishbase (2017b) indicates that the species is established in some locations, though as noted in the response to Q5, different databases present conflicting information, and as such they may or may not be supported by published literature and recent observations (see final sentence in the response to Q5). For example, the Daisie database (2015) says that *O. gorbuscha* is established in the European part of Russia, but both a paper by Petryashov *et al.* (2002) and

Fishbase (2017b) say that the species is not established. Also of note are the uncertain responses (probably yes, probably no) given in Elvira's (2001) review of fish introductions in Europe with regard to the establishment of this species in various countries.

This apparent uncertainty appears surprising. ICES (2013) reviewed the information on *O. gorbuscha* in Russia and confirmed that they were established. *Oncorhynchus gorbuscha* were introduced to the White Sea basin in the 1950s, with annual egg transfers from the far east of Russia to hatcheries in the Murmansk and Archangelsk regions (Gordeeva & Salmenkova 2011). However, despite over 20 years of introductions, no consistent natural reproduction occurred at that time, and the species disappeared when introductions stopped in 1979. This failure to establish was attributed to the use of populations from the southern part of the native range. It was suggested that these 'southern' *O. gorbuscha* began to spawn too late and eggs were lost as water temperatures in autumn were colder than those in their native habitat (Dyagilev & Markevich 1979). Successful natural reproduction only took place during some warmer years in the North Atlantic (Karpevich et al. 1991).

Oncorhynchus gorbuscha have the shortest life cycle among species of that genus, as they mature and reproduce after only two years. Therefore, there are two reproductively isolated populations that spawn in alternate even and odd years (Heard 1991). Introductions of odd-year *O. gorbuscha* to the White Sea basin were undertaken again in 1985, when a new brood-stock population was selected from the northern part of the species range – the Okhotsk Sea basin (Loenko et al. 2000). This single transfer of *O. gorbuscha* eggs resulted in the establishment of local self-reproducing populations in the White Sea rivers in the Murmansk and Archangelsk regions of Russia, where the adult returns fluctuated between 60 000 and 700 000 fish from 1989 through 2009 (Zubchenko et al. 2004; Gordeeva et al. 2005). However, transfers of eggs from even-year brood lines from the same river in the Okhotsk Sea basin proved largely unsuccessful. The last even-year egg transfer in 1998 resulted in a comparatively large return in the first generation, but abundance declined in subsequent generations and fish have only appeared in even years in small numbers since.

Oncorhynchus gorbuscha established in the White Sea basin support a commercial fishery, which takes place in coastal areas at the same time and using the same gears as the Atlantic salmon *Salmo salar* fishery. Catches of *O. gorbuscha* can exceed those of native *S. salar* in some years. For example, the total declared *O. gorbuscha* catch in 2009 was 139 tons, twice as much as the declared catch of *S. salar* from the same area (ICES 2010). No commercial fishery for *O. gorbuscha* is conducted in the White Sea in even years. The introductions in Russia have also resulted in *O. gorbuscha* catches in Norwegian waters (up to 20 tons in some years), with the species also becoming established in a number of rivers in N. Norway (Finnmark) (Hesthagen & Sandlund 2007; ICES 2013). Recent reports indicate that *O. gorbuscha* have been spawning widely across Norway in 2017 (K. Hindar, Norwegian Institute for Nature Research, pers. comm.), with >1500 *O. gorbuscha* have been caught in Norway by recreational or commercial fishermen from ≈200 rivers and in the sea. In extraordinary river fisheries, several thousand *O. gorbuscha* have been captured and removed before they spawn. It is possible that over 10 000 *O. gorbuscha* will be recorded from captures and drift diving counts in Norway in 2017 (I. Uglen, Norwegian Institute for Nature Research, pers. comm.). This pattern of expansion suggests a likely further spread from the Norwegian rivers where populations have already established. In Finland, there have been numerous observations in the River Teno (a.k.a. River Tina) of *O. gorbuscha* in high abundance in 2017, both in the large main stem and also in some tributaries. Anecdotal accounts from anglers catching 10–15 fish from the exact same spot. A detailed survey using two video camera arrays in two tributaries and a number of snorkelling counts in some other tributaries in Finland are planned for the last weeks of September 2017 to obtain more detailed, fishery-independent information about the distribution and abundance of *O. gorbuscha* this large river system (J. Erkinaro, Natural Resources Institute Finland, pers. comm.).

Recent evidence of *O. gorbuscha* reproduction in Scotland and rod capture reports from around England (see responses to questions 5 and 6) support the predicted 'medium' risk of becoming invasive in the UK, which was carried out using the Fish Invasiveness Screening Kit (FISK; Copp et al. 2009) based on information available in 2007–2008. A recent re-assessment of *O. gorbuscha*, using the 'Aquatic Species Invasiveness Screening Kit' (AS-ISK; Copp et al. 2016), which was developed from FISK to be more taxonomically generic and to comply with the 'minimum requirements' (Roy et al. 2017) for risk assessments under the new EU Regulation on the management of alien species (European Union 2014). The new invasiveness potential score for *O. gorbuscha*, based on the recent information in the present RRA and using the AS-ISK tool is 29, represents an increase of 12 points from the mean FISK score of 17.3 reported in Copp et al. (2009), which was based on two scores of 6 and 28.5. Recent comparisons of FISK and AS-ISK scores from two identical risk assessment areas found them to be similar (see Tarkan et al. 2017), so it is reasonable to assume that the invasiveness risk score for *O. gorbuscha* has shifted upwards from 'medium' (Copp et al. 2009) to 'high' (G.H. Copp, unpublished). Interestingly, the FISK score of 8 for southern Finland (based on information prior to 2013) is at the bottom of the 'medium' risk range (Puntila *et al.* 2013).

With regard to the 'impact' aspect of the term 'invasive', the species is said to exert adverse impacts in its introduced North American range (Fuller *et al.* 2015), these impacts being on species native to North America, but there appears to be relatively little information (if any) on impacts exerted by introduced *O. gorbuscha* on native fishes in general (see response to question 10), and in particular Atlantic salmon; this could explain why the species is listed on FishBase (2017a) under 'Threat to humans' as being 'Harmless'.

5 - What is the current distribution status of the organism with respect to the Risk Assessment Area?

Response: The native range of the species covers the northern Pacific coasts of North America and Asia, though in China it is also a translocated native species (Ma et al. 2003). This species has been introduced into Russia since at least the 1950s (ICES 2013), although other sources suggest later (Welcomme 1988; Holčík 1991; Hanel et al. 2007), spreading into Europe and the White/Barents Sea (Figs. 1 & 2). Recent information† indicates that an increasing number of individuals are being recorded caught off of Iceland, most Scandinavian countries, including Norway, where the species was introduced to Norway in the 1950s and by 2006/7 recorded at 11 locations presumed to be established populations (Hesthagen & Sandlund 2007) and Denmark, as well as Baltic countries such as Poland, where the species is not established (Grabowska et al. 2010), and Germany, where introductions apparently failed (Freyhof 2003) but at least three specimens were either captured or seen in August 2017 (M. Freese, Thünen Institute, pers. comm.). A specimen has also been captured in northern France, the River Canche, Pas-de-Calais, during July 2017 (Beaulaton et al. 2017). Recent reports indicate that unprecedented numbers, nearly 600, of *O. gorbuscha* have recently been captured from the River Vesterelva (Finnmarken county, North Norway), which is close to the Russian border (E. Niemelä, Natural Resources Institute, Finland, personal communication).

Initially listed as rare in the UK (Maitland 1987) and then as not established either in Great Britain 'Atlantic Ocean' or in England 'North Sea' (Daisie 2015; based on information cited as having been provide by Phil Lambdon, formerly of CEH). Potentially misleading information on introductions exist. Despite the species being classed as not established (Adams & Maitland 2001), FishBase (2017b) lists the UK as one of the countries where the species was introduced and is established, though evidence of this has only come to light in 2017 (see Question 6). Introductions to GB, whether intentional or unintentional remain unconfirmed, and this requires further investigation. Reports of the species for the GB date back as the 1960s (Wheeler & Blacker 1969; see also Figure 3): the first recorded specimen caught on 16 July 1960 in a bag net at Altens Fishing Station, on the Kincardine coast south of Aberdeen, then on 25 August 1960 a specimen was captured by rod and line above Workington Bridge on the River Derwent, Cumberland, followed by a third by net and coble from the River Tweed at Greenhill Fishery near Norhani on 19 July 1965, and then two specimens by sweep net at Bonar Bridge and at Stromness Voe, Shetland on 7 July 1967 and on 29 August 1967, respectively. Unconfirmed reports communicated by Wheeler & Blacker (1969) include two specimens at a netting stations on the Island of Skye and on the south coast of the Moray Firth, a specimen by bag net at Armdale (north coast of Scotland). More recently, ≈140 specimens have been captured in Scotland during 2017, mainly by rod and line but some in nets, and mostly in East coast rivers (Esk and Tweed), with hundreds of redds also found in the River Dee (B. Davidson & A. Wells, Fisheries Management Scotland, pers. comm.). The only record for Wales was a specimen captured in the Wye drift net fishery at Chepstow (just out in the Severn Estuary) in 1980 (P. Gough, Natural Resources Wales, pers. comm.).

Recent information for England (in 2017) includes confirmed rod captures of *O. gorbuscha* in north eastern rivers, including single specimens from the Coquet (Northumberland) and the River Tyne (Northumberland/ Durham) Driffield Beck (East Yorkshire), and two specimens from the Wear (Durham). Informal reports from net fishers in NE England describe a decline to zero of *O. gorbuscha* in the net fishery during the last few weeks of August 2017, as would be expected (J. Shelley, UK Environmental Agency, pers. comm.). In NW England, the first capture of a *O. gorbuscha* was reported this year for the River Duddon, South Cumbria (J. Shelley, pers. comm.). From south coast rivers, there are also confirmed rod captures of single specimens from the rivers Frome (Dorset) and Hampshire Avon (J. Shelley, pers. comm.). There have, however, been occasional earlier reports of *O. gorbuscha* captures in UK rivers, as far south as Cornwall (River Camel); these have always occurred in 'odd' years. In Ireland, the species is listed as a 'vagrant from stocking' (Minchin 2007), but 30 specimens having been recorded this year (Inland Fisheries Ireland 2017; ISI 2017) in nine Irish rivers beginning on 27 June from the Galway Weir fishery. In mid August 2017, a mature male, ready to spawn, was captured from the River Erriff in County Mayo (Inland Fisheries Ireland 2017).

† The above complemented by information in email correspondence received during July and August 2017 amongst the recently-established *O. gorbuscha* interest group comprising UK, Irish, and Scandinavian scientists.

Figure 1. Map (from Crawford & Muir 2007) illustrating the nati[illegible]nge (bl[illegible] diagonal), where spawning fish have been reported throughout, and primary distribution (black [illegible] of [illegible]ink salmon *Oncorhynchus gorbuscha*, with introduced range (red) by country or their internal terr[illegible] (i.e. state or province).

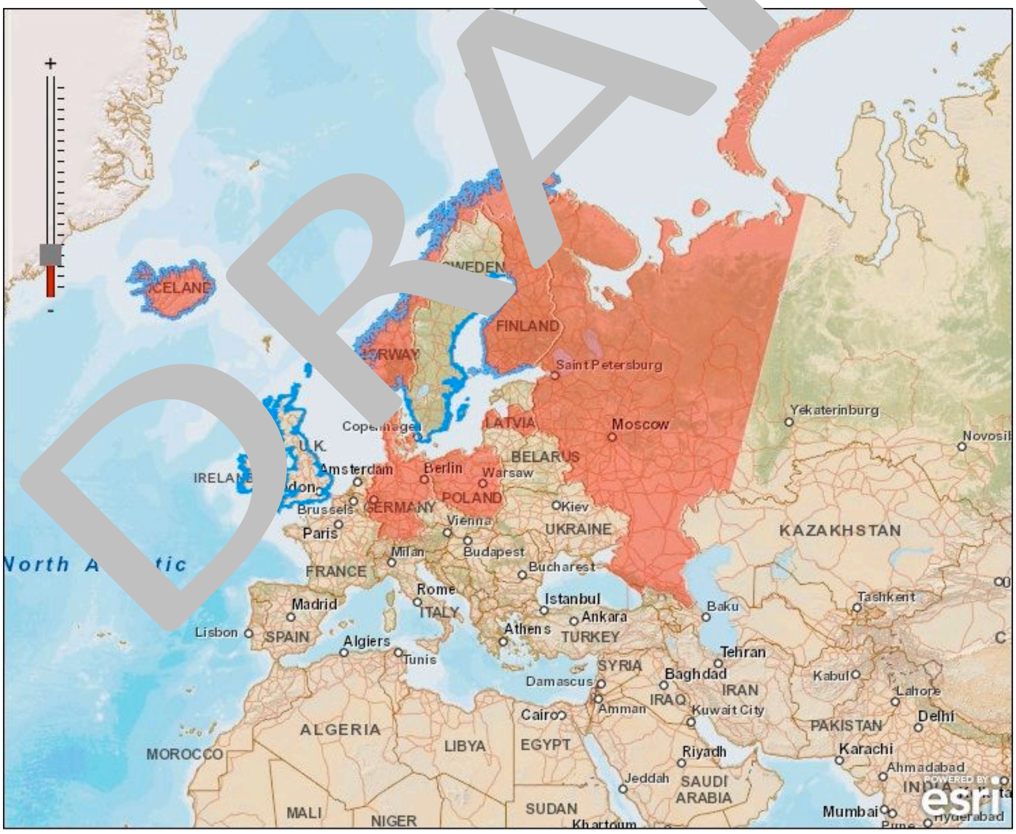

Figure 2. Map of the European distribution of *O. gorbuscha* from the Daisie (2015) database (terrestrial regions are shown in red and marine in blue).

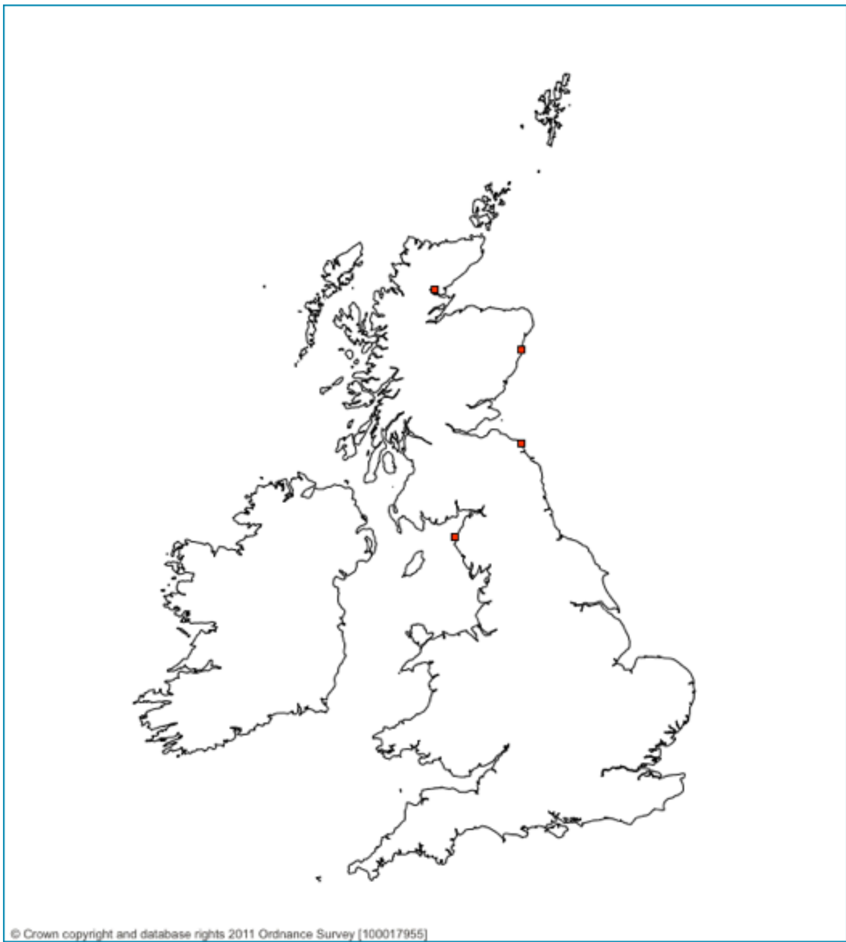

Figure 3. Map of *O. gorbuscha* distribution in GB (NBN 2015), which used data from the Database for Freshwater Fishes (DAFF 2002), which lists four entries cited as from Maitland (1972) but possibly originating from Wheeler & Blacker (1969).

6 - Are there conditions present in the Risk Assessment Area that would enable the organism to survive and reproduce? Comment on any special conditions required by the species?

Response: Yes, the increasing incidence of *O. gorbuscha* captures in Great Britain and Ireland, especially in 2017 would suggest that conditions are indeed suitable to the species. This is further substantiated by the scientific literature, including for water temperature (Table 1). The lower thermal limit for spawning in *O. gorbuscha* is ≈4 °C (Bailey & Evans 1971), the upper tolerance limit is 21°C (Eaton & Scheller 1996), though Jonsson & Jonsson (2009) give the upper critical temperature range to be: 21–28°C. In laboratory trials, *O. gorbuscha* preferred temperatures of 9.3–12.8°C, following acclimation at ≥15°C (Lyons et al. 2009). In a study to assess the potential establishment of non-native salmonids in upland streams, Dunmall et al. (2016) reported that streams with a minimum temperature of 4 °C during spawning and temperatures above 2°C during egg incubation were most vulnerable to *O. gorbuscha* establishment. A review of North American literature indicates that in general (i.e. generic North American data, mostly Canadian stocks) *O. gorbuscha* hatch in 40 days at 14°C, 47 days at 11°C, 72 days at 8°C, and 99 days at 5°C, with emergence in 72 days at 1°C, 91 days at 11°C, 120 days at 8°C, and 173 at 5°C (T.P. Quinn, University of Washington, pers. comm.).

For native salmonids in GB, the optimum range over which maximum egg hatch rates are observed are 4–7°C for *S. salar*, 1–8°C for *S. trutta* and 1–5°C for *S. alpinus* (Elliott & Elliott 2010; citing Peterson et al. 1977 and Humpesch 1985). These are similar to those for *O. gorbuscha*, and based on a brief search of stream temperatures in GB, there appear to be stream systems throughout GB that fulfil these requirements: e.g. upland streams of central Wales (0–16°C; Durance & Ormerod 2007); southern coast of England (e.g. Webb & Zhang 1999; Broadmeadow et al. 2010). The latter would appear to be partially supported by the recent rod captures of *O. gorbuscha* mentioned here above (in response to question '5') – although they do not provide evidence of reproduction, the presence of *O. gorbuscha* suggests conditions are generally suitable.

Previously thought to require salt water for completion of its life cycle, *O. gorbuscha* has been firmly established in the Great Lakes of North America following an accidental introduction into Lake Superior (Gharrett & Thomason 1987). These authors reported that allelic frequencies in the Great Lakes collections were consistent with a single introduction, with a decline in genetic variability, and that establishment of this unique, self-perpetuating, freshwater population may have been possible through selection for physiologically tolerant phenotypes.

Relative to the species native range, water courses in GB are relatively short. Although Reiser et al. (2006) stated that the extent of upstream migration by *O. gorbuscha* for spawning is said to be poorly studied. However, one of the cited references in their article, i.e. Heard (1991), stated that *O. gorbuscha* are typically thought to migrate a shorter distance up rivers to spawn than most other salmonids. Listing several sources, most from the Asian part of the species' native range, Heard (1991) reported on upstream spawning migration distances of 120, 160, 175, 200, 480, 694 and 700 km. This wide variation in distances suggests plasticity in terms of migratory distance for spawning. Spawning of *O. gorbuscha* takes place between June and September in the native range (Heard 1991), but since water temperature and elevated river discharge are key factors inciting upstream migration (as in many fishes), spawning migrations in GB are likely to be in earlier months of the year, as suggested from observations in the native range (Sheridan 1962). Recent anecdotal information (from fishers) for some rivers in both Southern and Northern Norway indicates that there seems to be a second run of *O. gorbuscha* migrating up river in September 2017, after the earlier arrivals have spawned (E. Thorstad, Norwegian Institute for Nature Research, pers. comm.).

Little heritability of embryo developmental rate was found in *O. gorbuscha* in terms of natal river temperature regime (Hebert et al. 1998), several sources report that alevins of *O. gorbuscha* can move almost directly into sea water (Jonsson & Jonsson 2009). This information suggests plasticity in reproduction and also limited time in fresh waters, thus reducing the likelihood of the young succumbing to elevated summer temperatures.

The information provided here above is complemented by very recent evidence (August 2017) of *O. gorbuscha* reproductive activity in the River Ness (Scotland). Figures 6.1, 6.2 and 6.3 here below are of two *O. gorbuscha* caught on the River Ness in the afternoon of 16 August (C. Conroy, Ness District Salmon Fishery Board/Ness & Beauly Fisheries Trust, pers. comm.). Very obvious is the pink hue on the underside on these two spent female 'kelts' (Figure 6.1), with only two eggs remaining in one of the fish (Figure 6.2). Both possess damage to their heads and caudal fins consistent with spawning activity. Carcasses of *O. gorbuscha* have also been reported along the river. Even more recent evidence from the River

Ness in September 2017 (C. Conroy, pers. comm.) includes the recovery from redds of ‘eyed ova’ (Figure 6.3) and empty egg shells indicative of spawning activity and successful fertilisation. These redds are believed to have been were created on 8 August at water temperatures on or around 15°C, with limited hatching observed 28 days later (C. Conroy, pers. comm.).

Figure 6.1. Spent female *O. gorbuscha* kelts captured in the River Ness on 16 August 2017.

Figure 6.2. The two female *O. gorbuscha* in Figure 6.1, one of which dissected to reveal the spent condition, with only two eggs found (Photo: C. Conroy).

These findings suggest that the peak spawning period of *O. gorbuscha* in the River Ness has passed, as camera footage taken on the same day (16 August) indicating that current activity in the river largely relates to territorial female kelts defending/tending to their redds (i.e. they continued to use their tails to ‘cut’ the gravel around their redds (C. Conroy, pers. comm.). Deposited eggs were recovered (Figure 6.3), evincing successful spawning.

Figure 6.3. Eyed eggs recovered from an excavated *O. gorbuscha* redd in the River Ness (Photo: C. Conroy).

Table 1. Critical temperatures (°C) for survival of different life stages of *Salmo salar, Salmo trutta, Salvelinus alpinus*, but with those added for *Oncorhynchus gorbuscha*. Incipient lethal temperature refers to the temperature beyond which species cannot survive indefinitely but it can tolerate (usually about 50% of the study specimens) for an extended interval (standard period = 7 days). Whereas, a temperature that cannot be tolerated by the fish for even a short interval (standard period = 10 minutes) is the ultimate lethal temperature (a.k.a. critical thermal maximum or minimum). Table re-drafted from Elliott & Elliott (2009), which should be consulted for original sources, with information on *Oncorhynchus gorbuscha* from Jonsson & Jonsson (2009), which cites Elliott (1994), † McCullough (1999; citing Brett 1952), ¥Bailey & Evans (1971) and §Beacham & Murray (1999), ¶Dunmall et al. (2016) gives minimum temperature as 2.0 °C).

	S. salar		*S. trutta*		*Sv. alpinus*		*O. gorbusha*	
	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper
Eggs	0	16	0	13	0	8	¥4.5	
Alevins								
Incipient	0–2.0	23–24	0–1.0	20–22	0–0.3	19–21	§3.5	§15–15.5
Ultimate	0–1.0	24–25	0	22–24	0–2.0	23–27	¶2.0	
Parr + smolt								
Incipient	0.2	22–28	0–0·7	22–25	0–1	22–23		†23.9
Ultimate	–0.8	30–33	–0·8	26–30	–1.0	26–27		21–28.0
Feeding	0–7.0	22–28	0·4–4.0	19–26	0.2	21–22		

7 - Does the known geographical distribution of the organism include ecoclimatic zones comparable with those of the Risk Assessment Area or sufficiently similar for the organism to survive and thrive?

Response: Yes. Examination of updated Köppen-Geiger maps (Peel *et al.* 2007) shows that the North American Pacific coast along Washington State (USA) and British Columbia (Canada) have areas of the same climatic zone as GB, i.e. "Cfb", which extends into most of the middle and northerly coasts of Continental Europe, including southern parts of Norway, where the species initially established itself following its introduction into the Barents Sea. This climatic zone does not appear to occur, however, along the Pacific coast of Asia.

8 - Has the organism established viable (reproducing) populations anywhere outside of its native range (answer N/A if you have answered 'yes' to question 4)?

Response: N/A

9 - Can the organism spread rapidly by natural means or by human assistance?

Response: Yes, *O. gorbuscha* is a migratory species, so dispersal by natural means is very likely, and there is also potential for dispersal by human assistance. There has previously been significant interest in the translocation of *O. gorbuscha* to establish new fisheries, given the species' life cycle and the expectation (assumption) that its presence would have little impact on *S. salar* (early migration of fry from freshwater, earlier spawning, etc.). Currently, however, this would seem to be less likely than spread via natural means. The recent evidence of reproduction in the River Ness, and the confirmed rod captures of *O. gorbuscha* mentioned here above for various parts of GB provide evidence of the species' ability to disperse naturally. In terms of this dispersal leading to the establishment of populations in the water courses visited by wandering *O. gorbuscha*, there is conflicting evidence as regards the necessity of pre-smolt imprinting of the natal stream. Ueda (2012) reported that *O. gorbuscha* may have evolved the capacity to select non-natal-stream odours during homing migration. Whereas, the review by Keefer & Caudill (2014) stated that pre-smolt imprinting is said to be essential for populations whose juveniles move rapidly to saltwater following emergence, such as *O. gorbuscha* (citing Heard 1996). However, Keefer & Caudill (2014) also note that a more simple population age structure, such as in *O. gorbuscha*, has been associated with less precise homing and higher straying because adults must find alternative habitats when conditions are poor at natal sites (citing Quinn 1993; Thorpe 1994). The Keefer & Caudill review also stated that species with shorter juvenile freshwater residency and shorter freshwater migration distances (e.g. *O. gorbuscha*) generally had higher straying rates from donor population than other species. *O. gorbuscha* are believed to stray more than other species, but hard evidence is lacking (Quinn 1997). A subsequent, circumstantial case study reported that hybrids, i.e. of odd and even year fish, exhibited elevated stray rates and reduced fitness relative to non-hybrids (Gilk et al. 2004).

10 - Could the organism itself, or acting as a vector, cause economic, environmental or social harm in the Risk Assessment Area?

Response: Yes, *O. gorbuscha* has been predicted to have a medium impact in the Great Lakes, at a 64% confidence level (Howeth et al. 2016). There is evidence that a biennial population cycle in planktivorous *O gorbuscha* can determine inter-annual variations in zooplankton and phyto-plankton (Shiomoto et al. 1997; Pace et al. 1999), which could have implications for zoo and phyto plankton in the invaded range. However, these effects were reported for freshwater ecosystems. More typically, *O. gorbuscha* fry migrate to sea in early summer, shortly after emerging from the gravel, hence any impacts on the freshwater ecosystem are only likely to occur for a short period in early summer. Adult *O. gorbuscha* do not feed after entering fresh waters (Heard, 1991), and hence predation on other species is not expected to occur. As such, the relatively rapid exodus of *O. gorbuscha* from natal rivers, fry feed less in fresh waters than other Pacific salmon, so any competition for food between *O. gorbuscha* and juvenile *S. salar* (or other species in fresh water) may only take place over a short period (ICES 2013).

There appears to be little evidence from Europe of adverse impacts, but information from the species' introduced range in North America, suggests *O. gorbuscha* is a potential vector of sea lice (Thrush et al. 2011), though the available information refers to infestations of wild stocks of the species when in proximity to coastal aquaculture facilities comprised of caged salmonids (Whelan 2010). As such, *O. gorbuscha* may exert adverse impacts on species native to GB, but this would need to be investigated. As mentioned above, spawning of *O. gorbuscha* is likely to take place in GB in earlier months than the June–September cited for the native range, which may reduce or eliminate the potential for competition with native salmonids, but this requires study. Given that *O. gorbuscha* typically migrate a shorter distance up rivers to spawn than most other salmonids (Heard 1991), and that spawning finishes before the spawning of *S. salar* starts, ICES (2013) noted a lack of any evidence to suggest interactions with *S. salar* at the spawning grounds, such as competition for spawning sites or destruction of redds. However, *O. gorbuscha* is known to out compete other salmonid species (Ruggerone & Nielsen 2004), which may be exerted in the RA area. For example, *O.*

gorbuscha in the White Sea region of Russia have been reported to prefer shallower areas and do not compete with *S. salar* for territory in big rivers, but that competition can occur in small rivers and in tributaries of large river systems when *O. gorbuscha* enter streams in large numbers and aggressively push overwintered autumn run *S. salar* out of holding pools to non-typical habitats (Zubchenko et al. 2004).

Although there is currently no evidence found of hybridisation between *Salmo* and *Oncorhynchus* species, hybridisation of species from these two Genera has apparently been achieved experimentally (Bozkurt & Yavaş 2014), but an earlier, preliminary study found that natural hybridisation of *O. gorbuscha* and *Salmo salar* would not occur (Loginova & Krasnoperova 1982).

Entry Summary

Estimate the overall likelihood of entry into the Risk Assessment Area for this organism (comment on key issues that lead to this conclusion).

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

Comments: The species is already present, having been reported in the wild the first time in the 1960s (Wheeler & Blacker 1969), and recent reports (see response to Q5) indicate increasing numbers in parts of GB, Ireland and adjacent areas of Scandinavia.

Establishment Summary

Estimate the overall likelihood of establishment (comment on key issues that lead to this conclusion).

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

Comments: The species has established self-sustaining populations outside its native range (the most convincing evidence thereof coming from North America, Russia and Norway). Recent evidence of successful spawning of *O. gorbuscha* in the River Ness (Scotland), which has been confirmed by the recovery of deposited, fertilised eggs (Figure 6.3) and of empty egg shells, suggests that the species' spawned eggs have successfully incubated and hatched (C. Conroy, pers. comm.), suggesting the potential to establish itself in river systems in GB, but whether or not this will result in self-sustaining populations remains to be determined (see Q6 response here above and also: www.facebook.com/FishtheNess/videos/1537874539605658/).

Spread Summary

Estimate overall potential for spread (comment on key issues that lead to this conclusion).

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

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*~~

Comments: It is clear that the species has exhibited capacity for natural spread following the initial human-facilitated releases in Russia. The species initially spread into relatively adjacent rivers in northern Norway over a period of two to three decades. However, the very large increase in reported sightings in 2017 of *O. gorbuscha* at large distances from Norway, as far south as southern England, and the reported widespread spawning of the fish across Norway, suggests a possible rapid escalation of the species' spread. It is currently unclear whether this represents a one-off event (e.g. due to particularly favourable conditions for spawning / early rearing) or reflects possible warming trends in the North Atlantic. In light of the increasing, recent reports of the species' in GB (see response to Q5), and the history of the species' presence in GB waters, spread has been, and probably is, intermediate (this assumption based on limited data).

It is virtually impossible to estimate how much suitable habitat could have already been occupied, based on limited opportunistic sightings of the fish in rivers and reported catches. My assumption is perhaps <5% occupancy at present, although this is highly uncertain. The salmonids from the Pacific undergo considerable migrations, as described here above, so dispersal by natural means may be taken as a given.

Impact Summary

Estimate overall severity of impact (comment on key issues that lead to this conclusion)

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

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: The assessment of impacts in risk analysis normally focuses exclusively on adverse impacts, with any beneficial impacts (e.g. commercial and/or recreational fishery revenues) being taken into consideration by decision makers. As for adverse impacts, it is difficult to estimate the severity of environmental, economic, social effects likely to be exerted in GB by *O. gorbuscha* due to the absence of information on introduced populations of this species in Europe. Information derived from North American studies may or may not be relevant due to the very different fish assemblages (Mahon 1984), and the introduced North American *O. gorbuscha* populations in the Great Lakes exist entirely in fresh waters, which represents a different environmental context to that of Europe. Most of the available information from North America focuses on the potential adverse impacts of non-native *S. salar* aquaculture on native stocks of Pacific salmonids (e.g. Whelan 2010; Marty 2015; Dill et al. 2015). Infectious agents are often associated with introduced fishes, but again evidence is lacking from European sources. Given the different spawning patterns and life-history characteristics of *O. gorbuscha* and native *S. salar*, ICES (2013) suggested that competition for spawning grounds or food during all post-hatch life stages was perhaps unlikely. However, it was recognised that there was a paucity of supporting evidence, and this possibility exists.

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: It is currently unclear whether the apparent step change in abundance of *O. gorbuscha* in 2017 (as evidenced by their widespread dispersal across the NE Atlantic) reflects climate-related effects. Above average temperatures were reported to be critical to the survival of early releases in Russia (as noted in Q4). Elevated temperatures arising from climate change might well enhance the abundance of existing established populations and increase the risk of further spread to rivers elsewhere, including those in GB.

The forecasted changes (increased hydrological variability, elevated water temperatures) arising from climate change are predicted to be disadvantageous for native brown trout *Salmo trutta* and Atlantic salmon *Salmo salar,* but catastrophic for native Arctic charr *Salvelinus alpinus* (Elliott & Elliott 2010). The likely effect on *O. gorbuscha* is mixed, with the warming conditions likely to dis-favour the species in southern parts of GB but potentially favour the species further north, as its temperature tolerances appear to be more plastic than those of *S. trutta* and *S. salar*. Such predictions are speculative, hence the low likelihood response and the low confidence level in that response. Note that the AS-ISK score of 29 for *O. gorbuscha*, using GB as the risk assessment area, mentioned here above (see response to question 4), decreases to 17 when the likely impact of climate warming conditions on the species' invasiveness was taken into account (G.H. Copp, unpublished).

CONCLUSION

Estimate the overall risk (comment on the key issues that lead to this conclusion).

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

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

Comments: Information is lacking on the species' impacts and/or interactions with native salmonids, with the only available information referring to disease (mainly sea lice) transmission between the native species (i.e. *O. gorbuscha*) and caged non-native *S. salar* (or *S. trutta*) in North America. The potential for impacts exists, but at this point, based on the available information, it is impossible to estimate the magnitude and extent of any impacts, as this would be speculative. Thus, at the current time, the impacts are estimated to be at the lower end of 'high' impact, but in contrast to medium-to-high confidence levels associated with the risks of Entry, Establishment and Spread, this estimate of likely impacts carries a low confidence ranking due to the limited evidence from North American and virtually complete absence of evidence from Europe. The potential risks posed by the species under conditions of climate warming are estimated to be low-to-medium, the lower risk being relevant to southern rivers of GB, and the moderate risk being relevant to those of northern GB, these estimates with a caveat of low confidence due to the lack of information on the species response to water temperatures under natural (as opposed to experimental) river conditions.

As with all risk assessments, the present rapid risk assessment is dynamic and therefore subject to revision in light of new evidence that may appear, even within days of this version of the RRA being released.

Management options (brief summary):

1 - Has the species been managed elsewhere? If so, how effective has management been?

Response: Information on management relates to conservation of the species in its native range, as some stocks of Pacific salmonids are experiencing similar declines (e.g. Puget Sound, Washington State, in 2017; T.P Quinn, pers. comm.) as the Atlantic salmonids in their native range, whereas some other stocks may be doing well.

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

Response: The only mention found regarding management as a non-native is the following, from Fuller et al. (2015):
"Unlike other Pacific salmon, pink salmon were not deliberately stocked for alewife biocontrol, nor are they deliberately stocked. Nonetheless, pink salmon descendants of an accidental release have become a valued part of the Great Lakes recreational fishery and they are managed alongside the other Pacific salmonids. Therefore, pink salmon management objectives are not geared towards the removal or eradication of the species like with most invaders."

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

Response: Prohibit importation, keeping and release. Raise awareness among stakeholder groups. Encourage correct identification, removal and killing of any specimens captured in the wild (e.g. dedicated fishery effort based on an eradication model).

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

Response: As soon as possible.

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