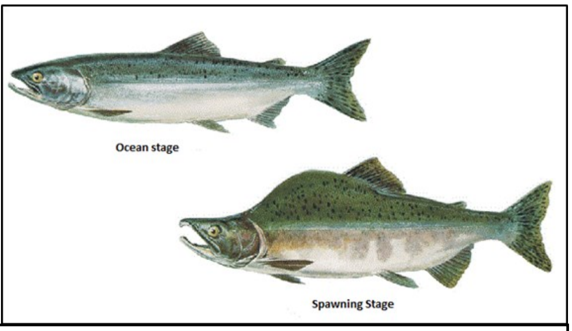
# Pink salmon (*Oncorhynchus gorbuscha*)

- Native to the northern Pacific ocean and coastal rivers of North America and Asia.
- Migrated to the UK from fishery stocks imported into Russia.
- Reported frequently in GB and successfully spawned in Scotland.
- Not yet thought to have established in GB, though potential for future establishment, particularly in Scotland.
- Carcasses may affect spawning native salmonids or disturb nests of sea lamprey; possible vector of sea lice.
- Appears only in odd-numbered years due to spawning patterns.

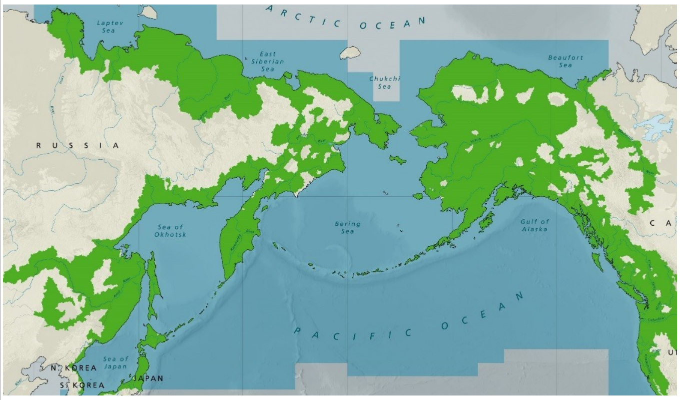



## History in GB

First recorded in 1960 in Scotland. In 2017, pink salmon were in at least 20 rivers in Scotland and Northern England and spawning activity was reported on at least two rivers with ‘hundreds of redds’ (spawning nests) being cut in the Dee.

## Native distribution

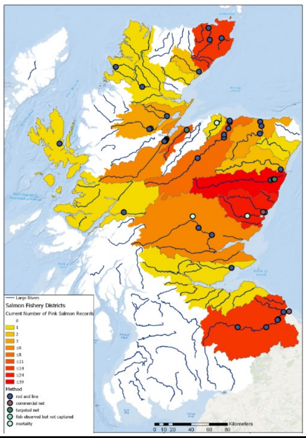
Pacific Ocean, Arctic Sea coast, and coastal rivers of North America and Asia




Source: State of the Salmon © 2005

## Distribution in GB

Extensive sightings in Scotland; multiple sightings in England

## Impacts

Environmental (moderate)
- Carcasses may affect native salmonids spawning, sea lamprey nests, or nutrient-sensitive pearl mussels.
- Possible vector of lice though sea lice in coastal aquaculture is likely to dissipate any dose response.

Economic (moderate)
- Possible decline in native salmonid commercial fisheries.
- Costs of monitoring and awareness-raising actions.

Social (moderate)
- Could impact rural areas with high dependence on fishing.
- Carcasses could create a negative experience for anglers.

## Introduction pathway

Migrants from Russian hatcheries in 1950s-70s established in most of the the Nordic countries, Latvia and Poland.

## Spread pathways

Natural (rapid) - High capacity for natural dispersion.

Human-aided (slow) – No legal pathways for introduction. Introductions would be illegal acts or stocking of contaminated supplies of Atlantic salmon or brown trout.

## Summary

| | Risk | Confidence |
|---|---|---|
| Entry | VERY LIKELY | HIGH |
| Establishment | VERY LIKELY | HIGH |
| Spread | RAPIDLY | HIGH |
| Impacts | MODERATE | LOW |
| Conclusion | MODERATE | MEDIUM |

# RISK ASSESSMENT COVERING PAGE - ABOUT THE PROCESS

**It is important that policy decisions and action within Great Britain are underpinned by evidence. At the same time it is not always possible to have complete scientific certainty before taking action. To determine the evidence base and manage uncertainty a process of risk analysis is used.**

Risk analysis comprises three component parts: risk assessment (determining the severity and likelihood of a hazard occurring); risk management (the practicalities of reducing the risk); and risk communication (interpreting the results of the analysis and explaining them clearly). This tool relates to risk assessment only. The Non-native Species Secretariat manages the risk analysis process on behalf of the GB Programme Board for Non-native Species. During this process risk assessments are:

- Commissioned using a consistent template to ensure the full range of issues is addressed and maintain comparable quality of risk and confidence scoring supported by appropriate evidence.
- Drafted by an independent expert in the species and peer reviewed by a different expert.
- Approved by the NNRAP (an independent risk analysis panel) only when they are satisfied the assessment is fit-for-purpose.
- Approved by the GB Programme Board for Non-native Species.
- Placed on the GB Non-native Species Secretariat (NNSS) website for a three month period of public comment.
- Finalised by the risk assessor to the satisfaction of the NNRAP and GB Programme Board if necessary.

**Common misconceptions about risk assessments**

The risk assessments:

- Consider only the risks (i.e. the chance and severity of a hazard occurring) posed by a species. They do not consider the practicalities, impacts or other issues relating to the management of the species. They also only consider only the negative impacts of the species, they do not consider any positive effects. They therefore cannot on their own be used to determine what, if any, management response should be undertaken.
- Are advisory and therefore part of the suite of information on which policy decisions are based.
- Are not final and absolute. They are an assessment based on the evidence available at that time. Substantive new scientific evidence may prompt a re-evaluation of the risks and/or a change of policy.

**Period for comment**

Once placed on the NNSS website, risk assessments are open for stakeholders to provide comment on the scientific evidence which underpins them for three months. Relevant comments are collated by the NNSS and sent to the risk assessor for them to consider and, if necessary, amend the risk assessment. Where significant comments are received the NNRAP will determine whether the final risk assessment suitably takes into account the comments provided.

**To find out more:** published risk assessments and more information can be found at http://www.nonnativespecies.org/index.cfm?pageid=143

# GB NON-NATIVE ORGANISM RISK ASSESSMENT SCHEME

**Name of organism:** *Oncorhynchus gorbuscha* - pink salmon
**Author:** Prof. Ian G. Cowx
**Risk Assessment Area:** Great Britain (England, Scotland, Wales and their islands)

**Version:** Draft 1 (*Jan 2018*), Peer review (*Feb 2018*), NNRAP 1$^{st}$ review (*Feb 2018*), Draft 2 (*May 2018*)
**Signed off by NNRAP:** June 2018
**Approved by Programme Board:** June 2019
**Placed on NNSS website**: *to be completed*

| **EU CHAPPEAU** | |
|---|---|
| **QUESTION** | **RESPONSE** |
| 1. In how many EU member states has this species been recorded? List them. | Finland<br>France<br>Germany<br>Iceland<br>Ireland<br>Latvia<br>Norway<br>Poland<br>Sweden<br>UK<br>European part of Russia<br>(Lithuania)<br>(Estonia)<br>(Romania)<br>(Bulgaria)<br>Countries in brackets identified in Crawford & Muir (2007) but no confirmation available.<br>Sources :<br>Nobanis: https://www.nobanis.org/species-info/?taxaId=2251<br>Daisie : http://www.europe-aliens.org/speciesFactsheet.do?speciesId=50232#<br>Crawford & Muir 2007; FAO DIAS |
| 2. In how many EU member states has this species currently established populations? List them. | Finland: Established (Nobanis, Daisie)<br>Iceland: Probably established (FAO DIAS)<br>Latvia: Established (Diasie)<br>Norway: Established (Nobanis)<br>Poland: Established (Daisie)<br>Sweden: Probably established (FAO DIAS) |

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| | European part of Russia: Established (Nobanis; Daisie)<br>Sources :<br>Nobanis : https://www.nobanis.org/species-info/?taxaId=2251<br>Daisie : http://www.europe-aliens.org/speciesFactsheet.do?speciesId=50232#<br>FAO DIAS |
| 3. In how many EU member states has this species shown signs of invasiveness? List them. | Finland: Established (Nobanis, Daisie)<br>Iceland: Probably established (FAO DIAS)<br>Latvia: Established (Diasie)<br>Norway: Established (Nobanis)<br>Poland: Established (Daisie)<br>Sweden: Probably established (FAO DIAS)<br>European part of Russia: Established (Nobanis; Daisie)<br>UK<br>Ireland<br>Sources :<br>Nobanis : https://www.nobanis.org/species-info/?taxaId=2251<br>Daisie : http://www.europe-aliens.org/speciesFactsheet.do?speciesId=50232#<br>FAO DIAS |
| 4. In which EU Biogeographic areas could this species establish? | Rivers in:<br>Atlantic North<br>Atlantic Central<br>Baltic Sea<br>North Sea |
| 5. In how many EU Member States could this species establish in the future [given current climate] (including those where it is already established)? List them. | All countries along the Atlantic Ocean, Baltic Sea and North Sea seaboards are liable to invasion from the species spreading south from the original stocking in the White Sea region of northern Russia from the 1950s until 2003 and establishment in Norway and Finland. Romania and Bulgaria are not included because there is no confirmed evidence the species has been recorded in these countries.<br>Belgium |

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| | Estonia<br>Finland<br>France<br>Germany<br>Iceland<br>Ireland<br>Latvia<br>Lithuania<br>Norway<br>Poland<br>Sweden<br>The Netherlands<br>UK |
| 6. In how many EU member states could this species become invasive in the future [given current climate] (where it is not already established)? | All countries along the Atlantic Ocean, Baltic Sea and North Sea seaboards are liable to invasion from the species spreading south from the original stocking in the White Sea region of north Russia from the 1950s until 2003, and the establishment in Norway and Finland.<br>Belgium<br>Estonia<br>Finland<br>France<br>Germany<br>Iceland<br>Ireland<br>Latvia<br>Lithuania<br>Norway<br>Poland<br>Sweden<br>The Netherlands<br>UK |

| SECTION A – Organism Information and Screening | | |
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| **Stage 1. Organism Information** | **RESPONSE** | **COMMENT** |
| 1. Identify the organism. Is it clearly a single taxonomic entity and can it be adequately distinguished from other entities of the same rank? | Yes | Pink salmon *Oncorhynchus gorbuscha* Walbaum (Synonyms: *Oncorhynchus scouleri* (Richardson), *Salmo gorbuscha* Walbaum, *Salmo scouleri* Richardson) is a single taxonomic entity of the Family Salmonidae and the Pacific salmon genus *Oncorhynchus*. Its colouring changes from silver to pale grey on the back with yellowish-white belly. The fish is characterized by a white mouth with black gums, large oval-shaped black spots on the back, a v-shaped tail, and an anal fin with 13-17 soft rays and black spots. Very small scales – much smaller than a similarly-sized Atlantic salmon. Upper jaw typically extending beyond the eye. Once in freshwater, pink salmon take on a dark green colouration and male fish develop a distinctive hump. *O. gorbuscha* average 2.2 kg in weight; maximum recorded size 76 cm and 6.8 kg (FAO species fact sheet http://www.fao.org/fishery/species/2116/en)  Figure 1. Adult male pink salmon (Photo: Alan Wells and John Armstrong) |
| 2. If not a single taxonomic entity, | Not applicable | |

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| can it be redefined? (if necessary use the response box to re-define the organism and carry on) | | |
| 3. Does a relevant earlier risk assessment exist? (give details of any previous risk assessment) | Yes | Copp (2017) Rapid Risk Assessment of: *Oncorhynchus gorbuscha* (Walbaum) (pink or humpback salmon). GB Non-native Species Rapid Risk Assessment (NRRA), Cefas, Lowestoft. Draft (10 August 2017) |
| 4. If there is an earlier risk assessment is it still entirely valid, or only partly valid? | Entirely valid | Previous version undertaken but Copp (2017) was a rapid, although comprehensive assessment. It included an assessment using the 'Aquatic Species Invasiveness Screening Kit' (AS-ISK; Copp et al., 2016), which was an update of an assessment carried out using the Fish Invasiveness Screening Kit (FISK; Copp et al., 2009) based on information available in 2007–2008. The 2017 analysis scored the invasiveness potential for *O. gorbuscha* as high, elevating the score from medium in the previous FISK assessment. |
| 5. Where is the organism native? | | *O. gorbuscha* has a preferred temperature range of 5.6 to 14.6°C, an optimal temperature of 10.1°C, and an upper lethal temperature of 25.8°C (Heard 1991; Quinn, 2005, 2018). Its native range is northern Pacific Ocean and Bering Sea north of approx. 40°N and rivers of North America and Asia from the Sacramento River in northern California to the Mackenzie River in Canada, although there are suggestions that that there are no self-sustaining populations south of Columbia River (Nielsen and Ruggerone 2013; Peiman 2018). In the west the species ranges from the Lena River in Siberia to Korea and Honshu in Japan. (See Figure 1). |
| 6. What is the global distribution of the organism (excluding Great Britain)? | | Introduced into rivers affluent to the White and Barents Seas (1956-63, 1967-75), with annual egg transfers from the far east of Russia to hatcheries in the Murmansk and Archangelsk regions (Gordeeva & Salmenkova, 2011). The species is now more widespread, the stocks are maintained by both natural spawning and further stocking; it is well established in Norwegian rivers from Ob to Finnmark, but straying further south; records from southern Norway and south-eastern Sweden may have been strays from stocking in Bay of Riga. Migrants have also been found in Western Europe, including Germany, France, Ireland and possibly the Baltic States and Poland (Berg, |

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| | | 1962; Welcomme, 1988; Holčík, 1991; Hanel et al., 2007).<br><br>*O. gorbuscha* is found in China, where it is considered a translocated native species (Ma *et al*., 2003) and feeding migrants are common along the coast of northern Japan and the Sea of Japan.<br><br>*O. gorbuscha* has established in the Great Lakes of North America (Kwain 1987; Fuller et al., 2015), following an accidental introduction into Lake Superior (Gharrett & Thomason, 1987), and in Chile and Argentina (Welcomme, 1988; Castilla & Neill, 2009), although numbers in the Great Lakes are declining in recent years (Bo Bunnell USGS, pers comm.). In Europe, *O. gorbuscha* has been periodically introduced to rivers of the White Sea and Barents Sea basins in Russia since 1956. Stray fish, presumed from these rivers, have been encountered ascending rivers in Norway, Sweden, Great Britain and Iceland, and self-sustaining populations have been observed in Norway and Iceland. (See Figure 1) |
| 7. What is the distribution of the organism in Great Britain? | | There is no confirmed introduction of *O. gorbuscha* into GB, whether intentional or unintentional. Reports of the species for the British Isles date back to the 1960s (Wheeler & Blacker, 1969; Maitland, 1972; 1987; see also Figure 2). The first recorded specimen was caught on 16 July 1960 in a bag net at Altens Fishing Station, on the Kincardine coast south of Aberdeen followed by others caught by rod and line above Workington Bridge on the River Derwent, Cumberland (25 August 1960), by net and coble from the River Tweed at Greenhill Fishery near Norham (19 July 1965), and two specimens by sweep net at Bonar Bridge, Sutherland and at Stromness Voe, Shetland (7 July and 29 August 1967, respectively). Further, unconfirmed reports were noted by Wheeler & Blacker (1969) included two specimens at a netting station on the Island of Skye and another in the bag net at Armdale on the south coast of the Moray Firth (north coast of Scotland).<br><br>Pink salmon have been reported to be present in at least 18 Scottish rivers, according to Fisheries Management Scotland, by DSFBs and Fisheries Trusts in 2017. There are also reports of spawning activity and redds being cut on at least four rivers in Scotland, the Ness, Spey, Thurso and Dee, with ‘hundreds of redds’ being cut in the latter in 2017 (A. Wells, Fisheries Management Scotland, reported in Copp, 2017). Significant |

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| | | numbers of fish were also captured in coastal nets in Montrose, although exact numbers are not available. In England, pink salmon have been reported from the sea and tidal rivers in Yorkshire and the North East. In 2017, about 200 *O. gorbuscha* were caught in the Yorkshire and North East coastal net fishery and several have been caught by individual anglers in the River Coquet (Northumberland), the River Tyne (Northumberland/ Durham), Driffield Beck, a tributary of the River Hull (Humber catchment; East Yorkshire), and two specimens from the River Wear (Durham). *O. gorbuscha* has also been reported for the first time in 2017 in the River Duddon, South Cumbria and from the south coast rivers Frome (Dorset) and Hampshire Avon (J. Shelley, UK Environmental Agency, pers. comm. to G.R. Copp). There are, however, occasional earlier reports of *O. gorbuscha* captures in UK rivers, as far south as Cornwall (River Camel); these have always occurred in odd-numbered years. This odd-even numbered years is relevant because the species has a characteristic two-year life cycle, and in the native range the odd-year and even-year lines are distinct genetically and also numerically in many rivers.<br><br>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, reported in Copp, 2017).<br><br>In Ireland catches of *O. gorbuscha* have been reported in 10 rivers including on the Foxford Fishery, Co. Mayo, the Coolcronan Fishery on the River Moy, the Galway Fishery on the River Corrib, the Cong River on the River Corrib and the Drowes River in Donegal. In Ireland, the species is listed as a 'vagrant from stocking' (Minchin, 2007). |
| 8. Is the organism known to be invasive (i.e. to threaten organisms, habitats or ecosystems) anywhere in the world? | Yes | Over the last 10 years *O. gorbuscha* has successfully bred in rivers in Norway and Iceland and they may now be crossing the North Sea to GB where they have successfully spawned and hatched in 2017, but it is not known whether the hatchlings from the wild are viable or survived. |
| 9. Describe any known socio-economic benefits of the organism | | *Oncorhynchus gorbuscha* established in the White Sea basin supports a commercial fishery; catch in 2009 was 139 t, although catches in even numbered years are low |

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| in the risk assessment area. | | (ICES, 2010). The introductions in Russia have also resulted in *O. gorbuscha* catches in Norwegian waters (up to 20 t in some years), with the species also becoming established in a number of rivers in N. Norway (Finnmark) (Hesthagen & Sandlund, 2007; ICES, 2013).<br><br>Catches of pink salmon contribute to recreational rod fisheries in Northern Europe and could potentially contribute in GB. They have also been caught in commercial coastal netting stations in Scotland and the NE drift net fisheries in England. However, as in their native range, they are likely much lower in value per weight than Atlantic salmon. |

**Figure 1.** Map illustrating native range (black diagonal), where spawning fish have been reported

ıynchus gorbuscha, with introduced range (red) by country or their internal territory (i.e. state or

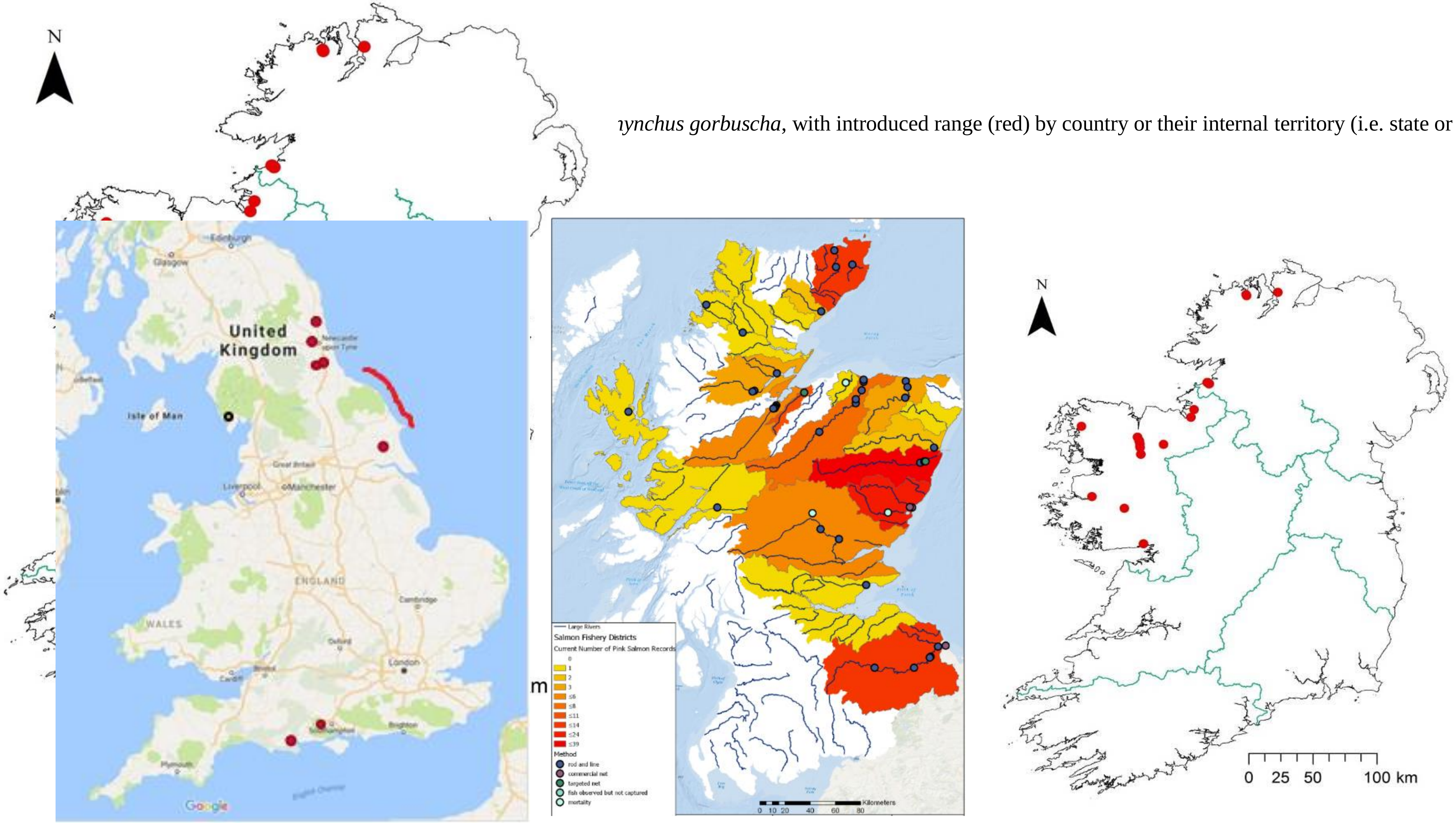


**Figure 2**. Maps of England and Wales, Scotland and Ireland showing the distribution of catches of *O. gorbuscha* based on reports/presentations to GB Invasive Species/SNH meeting Edinburgh - 21 September 2017

| **Stage 2. Screening Questions** | | |
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| 10. Has this risk assessment been requested by the GB Programme Board? (If uncertain check with the Non-native Species Secretariat) | Yes<br>If yes, go to section B (detailed assessment)<br>If no, got to 10 | |

## SECTION B – Detailed assessment

# PROBABILITY OF ENTRY

Important instructions:

- Entry is the introduction of an organism into GB.  Not to be confused with spread, the movement of an organism within GB.
- For organisms which are already present in GB, only complete the entry section for current active pathways of entry or if relevant potential future pathways.  The entry section need not be completed for organisms which have entered in the past and have no current pathways of entry.

| QUESTION | RESPONSE [chose one entry, delete all others] | CONFIDENCE [chose one entry, delete all others] | COMMENT |
|---|---|---|---|
| 1.1. How many active pathways are relevant to the potential entry of this organism?<br><br>(If there are no active pathways or potential future pathways respond N/A and move to the Establishment section) | few | high | Three potential pathways.<br>1) Intentional transfer and introduction by humans (e.g. stocking, creation of new fishery).<br>2) Dispersal from previous introductions in region.<br>3) Escape from aquaculture facilities.<br>Dispersal from previous introduction (#2), notably from the White Sea introductions in Russia, rather than through introduction or escape, is probably the most likely pathway. |
| 1.2. List relevant pathways through which the organism could enter.  Where possible give detail about the specific origins and end points of the pathways.<br><br>For each pathway answer questions 1.3 to 1.10 (copy and paste additional rows at the end of this section as necessary). | Three potential pathways | | 1) Intentional transfer and introduction by humans (e.g. stocking, creation of new fishery).<br>2) Dispersal from previous introductions in region.<br>3) Escape from aquaculture facilities.<br>Dispersal from previous introduction, notably from the White Sea introductions in Russia is probably the most likely pathway. |
| Pathway name: | **1) Intentional transfer and introduction by humans (e.g. stocking, creation of new fishery)**. | | |
| 1.3. Is entry along this pathway intentional (e.g. the organism is imported for trade) or accidental (the | intentional | high | There is no approved, or likely to be approved, introduction of *O. gorbuscha* into GB or north and |

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| organism is a contaminant of imported goods)?<br><br>(If intentional, only answer questions 1.4, 1.9, 1.10, 1.11) | | | northwest European waters. Any direct introductions will be deliberate, illegal acts or possible stocking of contaminated supplies of Atlantic salmon, brown trout or rainbow trout, although the latter is highly unlikely. If the species were introduced it would likely result in establishment similar to the scenario in Russia where thousands of *O. gorbuscha* were introduced to the White Sea region of northern Russia and the Kola Peninsula between 1950 and 2003 to develop a commercial net fishery (Zubchenko et al., 2004; Gordeeva et al., 2005). This has resulted in large, self-sustaining populations in the White Sea (e.g. 100 tonnes in R Varzuga alone, 2017). The species has now established self-sustaining populations in rivers in Russia, Iceland and Norway, and *O. gorbuscha* have spawned in the rivers Dee, Spey and Ness in Scotland in 2017: eggs have hatched *in situ* (egg boxes within affected rivers) and in controlled hatchery conditions. |
| 1.4. How likely is it that large numbers of the organism will travel along this pathway from the point(s) of origin over the course of one year?<br><br>Subnote: In your comment discuss how likely the organism is to get onto the pathway in the first place. | very likely | high | Given the low potential for *O. gorbuscha* to be introduced into GB or European waters (Q1.3) it is unlikely that the species will enter along this pathway, but should it occur the likelihood for dispersion around GB would be high if the species was able to establish in GB rivers.<br><br>It is thought *O. gorbuscha* found in European waters originated from the stocking in the White Sea region of northern Russia and the Kola Peninsula between 1950 and 2003 and the species has systematically dispersed over recent decades (see Figure 3), and resulted in the establishment of self-sustaining populations in Finland, Norway and Iceland.<br><br>Occasional fish have been reported in the other Northern European countries (see Q1.1) since the 1960s, including GB, and occasionally fish have been reported in the North |

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| | | | East Coast salmon drift fishery since the mid-1980s. The proliferation in GB in 2017 is likely the result of introductions and 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)), and subsequent dispersion and establishment of populations in Norway (Bjerknes, 1977; K. Hindar, Norwegian Institute for Nature Research, pers. comm.) (see Figure 3). Reports indicated that *O. gorbuscha* spawned widely across Norway in 2017 (K. Hindar, Norwegian Institute for Nature Research, pers. comm., reported in Copp, 2017) suggesting possible further spread from the Norwegian rivers where populations have already established. |
| 1.5. How likely is the organism to survive during passage along the pathway (excluding management practices that would kill the organism)?<br><br>Subnote: In your comment consider whether the organism could multiply along the pathway. | very likely | medium | *O. gorbuscha* has systematically dispersed and established in rivers along the dispersion pathway from the White Sea through the north east Atlantic (see Figure 3). This will likely increase the propensity for further dispersion and invasion south. Should *O. gorbuscha* successfully invade into GB it is likely to survive given its already wide dispersion in GB. Much will depend on the adaptive capacity of the species to establish based on its origins and odd-even-numbered year reproductive cycle versus climatic conditions in fresh water and at sea (Pathway 2, Q1.3). In addition, marine survival of smolts entering the estuary and coastal areas will likely depend on suitable feeding opportunities in this early life stage. |
| 1.6. How likely is the organism to survive existing management practices during passage along the pathway? | likely | high | Strict quarantine and border regulations are in place to prevent imports of non-native species and EU Regulation 207/2008 should preclude the introduction of a new species for aquaculture (and thus stocking) purposes but *O. gorbuscha* is not specifically named in EU Regulation |

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| | | | 207/2008 or EU Regulation 1143/2014 on Invasive Alien Species. However, the capacity for Border Agencies to detect eggs or juvenile *O. gorbuscha* from native or already introduced salmonid species is limited so, it is possible that they could enter GB undetected.<br><br>No management interventions are in place along the invasion pathway should the species establish in open waters, although active fishing and culling of adults and raking of redds is carried out in Norway and is being considered for GB. No assessment with regard to the efficacy of these approaches has been carried out. |
| 1.7. How likely is the organism to enter GB undetected? | very likely | very high | Given the low capacity of the Border Agencies to detect consignments of *O. gorbuscha* or amongst contaminated consignments of other salmonids, the species could enter the country undetected for illegal aquaculture and stocking purposes. If established, there is considerable evidence to suggest that the species would be detected as it has been found across Scotland and along the East Coast of England as far as the Humber with the odd stray fish being recorded as far south as Cornwall. It is highly likely the species has a wider distribution range than present, but has not as yet been detected, unless caught by anglers familiar with the species. The EA and SEPA are undertaking awareness campaigns and requesting anglers to report any *O. gorbuscha* caught. These campaigns should be extended to include campaigns targeting fishery owners, fishery managers and fish farm operators, to highlight the impact of introductions and the illegal nature of such activities.<br><br>In addition, until fisheries surveys are conducted specifically to detect the presence of juvenile pink salmon, it is likely they will be overlooked, especially as the species often spawns in lower streams associated with |

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| | | | estuarine waters (T. Quinn, pers. comm.) This is confirmed by K.W. Vollset (University of Bergen), who indicate that the fish were present in all of the rivers around Bergen following spawning they seem to staying in fresh waters longer than expected (i.e. migrate out after their yolk was spent, which is the normal expectation), and seem to be waiting from some sort of cue. |
| 1.8. How likely is the organism to arrive during the months of the year most appropriate for establishment? | very likely | very high | Introductions into GB will depend on the life stage being imported. Given the well developed technology to transport *O. gorbuscha* associated with existing stockings and introductions, the likelihood of survival to the point of introduction is high. |
| 1.9. How likely is the organism to be able to transfer from the pathway to a suitable habitat or host? | very likely | high | The establishment of *O. gorbuscha* in new habitats seems to be very much dependent on the thermal conditions and access to and availability of suitable spawning habitat in rivers in the invasion area. Recent observations of spawning activity of *O. gorbuscha* in the rivers Ness, Spey and Dee (Scotland) in 2017, and recovery of deposited, fertilised and empty egg shells from the Ness (C. Conroy, pers. comm. In Copp, 2017) and Spey (B. Shaw, pers.obs.) suggests that the species has successfully spawned, and eggs have successfully incubated and hatched. In addition, pink salmon eggs that have been successfully hatched in *in situ* egg boxes in these rivers have been kept to the point where the egg sacs have been almost completely absorbed, suggesting these fish are about to become pink salmon smolts and thus complete the freshwater life stage of species (C. Conroy & B. Shaw, pers. obs.). The existence of successful spawning and hatching indicates the species has the potential to establish itself in GB river systems, particularly in Scotland where the habitat and environmental characteristics are similar to its home range, but whether or not this will result in self-sustaining populations remains to be determined as there is |

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| | | | no record of juvenile *O. gorbuscha* being caught. Checking whether the newly hatched alevins grow to parr and subsequently adults in the wild will likely require extensive electric fishing and angler and netting catch surveys, supplemented by genetic studies. eDNA studies are not deemed appropriate because the adults and eggs are already present in the system and, because the methodology is not life-stage specific, it may not necessarily detect the presence of viable juvenile progeny.<br><br>It should be noted that there are many unsuccessful efforts to transplant the species within its natural range, e.g. to Newfoundland (Lear 1980) and even-year runs to Puget Sound (as reviewed by Withler 1982), so transplanting fish will not necessarily result in establishment. |
| 1.10. Estimate the overall likelihood of entry into GB based on this pathway? | unlikely | very high | There is no evidence of the introduction and/or direct stocking of *O. gorbuscha* in GB or northern and western Europe, although there was interest in doing this in previous years. Despite the species being the target of valuable commercial fisheries within its home range, there is no recorded deliberate introduction into European fresh waters, either legally or illegally. Any introduction would be either illegal and pre-meditated or, possibly, accidental if they were included in a contaminated consignment of Atlantic salmon or brown trout eggs or juvenile fishes. There is no way to account for pre-mediated illegal introductions, but awareness campaigns could help reduce the likelihood of introductions through this pathway. |
| **Pathway name:** | **2) Dispersal from previous introductions in region** | | |
| 1.3. Is entry along this pathway intentional (e.g. the organism is imported for trade) or accidental (the organism is a contaminant of imported goods)? | accidental | very high | Many thousands of *O. gorbuscha* were introduced to the White Sea region of northern Russia and the Kola Peninsula between 1950 and 2003 to develop a commercial net fishery. This has resulted in large self- |

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| (If intentional, only answer questions 1.4, 1.9, 1.10, 1.11) | | | sustaining populations in the White Sea (e.g. 100 t in the River Varzuga alone).<br><br>The species has now established self-sustaining populations in rivers in Russia, Iceland and Norway, and *O. gorbuscha* have spawned in the rivers Dee, Spey and Ness in Scotland in 2017 and advanced-stage alevins with yolk sac almost fully absorbed have been recovered from egg boxes in both the rivers Spey and Ness. Eggs recovered from the River Dee have been successfully hatched in controlled conditions. The introductions in Russia are thought to have resulted in catches of *O. gorbuscha* in Norwegian waters (up to 20 mt in some [odd-numbered] years). |
| 1.4. How likely is it that large numbers of the organism will travel along this pathway from the point(s) of origin over the course of one year?<br><br>Subnote: In your comment discuss how likely the organism is to get onto the pathway in the first place. | very likely | high | It is presumed that *O. gorbuscha* in European waters originates from the stocking in the White Sea region of northern Russia and the Kola Peninsula between 1950 and 2003 and the species has systematically dispersed over recent decades (see Figure 3),. This has resulted in the establishment of self-sustaining populations in Norway and Iceland. The species has a strict (almost invariant) two-year life cycle during which they mature and reproduce. Juveniles typically migrate immediately to sea after emerging from the gravel redds at a size of 30 mm and weighing 0.2 g. In the native range there is virtually no period of freshwater rearing (i.e., in streams). They can feed as they move through lakes and grow rapidly (Robins et al. 2005) but this is unusual. The time spent in estuarine and coastal areas can be variable although this could be up to 5-6 months depending on the time of spawning. After moving into the open sea, these fish return to spawn as 2-year old adults and then die. Consequently, there are two reproductively isolated populations that spawn in alternate even and odd numbered years (Heard, 1991); fish produced in odd years will never overlap with fish |

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| | | | produced in even years, although it should be noted that under conditions of very slow growth, as in the Great Lakes, pink salmon may delay maturity to age 3 and so a line that began on one cycle (even or odd) can diverge (Nicolette and Spangler 1986).<br><br>It appears the stock that has established in the White Sea rivers in the Murmansk and Archangelsk regions of Russia is based on an odd-numbered year introduction 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; Zubchenko et al., 2004; Gordeeva et al., 2005, 2015). Transfer 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 since only appeared in small numbers in even years. There is debate that the reason for the failure of the even year stockings is because they are from a less well adapted stock from very northern, colder water, origin and thus less well adapted to conditions in the invasion area. (Loenko et al., 2000).<br><br>The proliferation of *O. gorbuscha* in GB in 2017 is likely the result of introductions and 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)), and subsequent dispersion and establishment of populations in Norway (see Figure 3). This is likely because the species has a greater tendency to stray (i.e. return to non-natal sites for spawning) than that of other salmon, or at least it has the capacity to spread quickly (e.g., Pess et al. 2012). Reports indicated that *O.* |

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| | | | *gorbuscha* spawned widely across Norway in 2017 (K. Hindar, Norwegian Institute for Nature Research, pers. comm., reported in Copp, 2017). Adult pink salmon were observed in at least 256 Norwegian rivers from the Russian border in the northeast to the Swedish border in the southeast, spanning 13 degrees latitude. This possibly suggests further spread from the Norwegian rivers where populations have already established. |
| 1.5. How likely is the organism to survive during passage along the pathway (excluding management practices that would kill the organism)?<br><br>Subnote: In your comment consider whether the organism could multiply along the pathway. | very likely | high | *O. gorbuscha* has systematically moved and established in rivers along the dispersion pathway from the White Sea through the north east Atlantic (see Figure 3), including in Norway. Specimens have been caught in northern European countries (see Section EU Chappeau Q1) since the 1960s, including GB, and occasionally fish have been reported in the North East Coast salmon drift fishery since the mid-1980s.<br><br>The establishment in new locations, specifically in Norwegian rivers, will likely increase the propensity for further dispersion and invasion south, including to GB. Much will depend on the adaptive capacity of the species to establish based on its origins and odd-even year reproductive cycle versus climatic conditions (Pathway 2, Q1.3). For example, Dyagilev & Markevich (1979) suggested that *O. gorbuscha* from more southern populations begin to spawn too late and eggs are lost as water temperatures in autumn are colder than those in their native habitat, and Karpevich et al. (1991) only found successful natural reproduction during some warmer years in the North Atlantic. In addition, marine survival of smolts entering the estuary and coastal areas will likely depend on suitable feeding opportunities in this early life stage. |
| 1.6. How likely is the organism to survive existing | very likely | high | No management interventions are in place along the |

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| management practices during passage along the pathway? | | | invasion pathway, although active fishing and culling of adults and raking of redds is carried out in Norway and is being considered for GB. No assessment with regard to the efficacy of these approaches has been carried out.<br><br>It appears that Russia has ceased stocking *O. gorbuscha* since 2003, although this is not confirmed. The presumed self-sustaining populations are the target of fisheries in the White Sea area and are harvested as by-catch in commercial fisheries and exploited by anglers in rivers where they are found across their European distribution range. |
| 1.7. How likely is the organism to enter GB undetected? | unlikely | medium | There is considerable evidence that the species is present across Scotland and along the east coast of England as far as the Humber with the odd stray being found as far as Cornwall, the latter particularly in the past. It is highly likely the species has a wider distribution range, but is as yet not detected because anglers are unfamiliar with the species and may not be targeting them. Also there is evidence that anglers report catches many months after capture suggesting many may go unreported (J. Shelley, pers. comm.). The EA and SEPA are undertaking awareness campaigns and requesting anglers to report any *O. gorbuscha* caught.<br><br>In addition, until fisheries surveys are conducted specifically to detect the presence of juvenile pink salmon, it is likely they will be overlooked, especially as the species often spawns in lower streams associated with estuarine waters (T. Quinn, pers. comm.) This is confirmed by K.W. Vollset (University of Bergen), who indicate that the fish were present in all of the rivers around Bergen following spawning they seem to staying in fresh waters longer than expected (i.e. migrate out after their yolk was spent, which is the normal expectation), and |

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| | | | seem to be waiting from some sort of cue. |
| 1.8. How likely is the organism to arrive during the months of the year most appropriate for establishment? | very likely | very high | *O. gorbuscha* is a diadromous species with a two-year life cycle and typically spawns in July-October in its native range. The large number of *O. gorbuscha* reported in GB in the summer of 2017 suggests that the species will arrive in GB rivers at a time suitable for successful reproduction and evidence of successful spawning and hatching (although not necessarily recruitment) in the rivers Ness, Spey and Dee indicate the species would be present at the most appropriate for establishment. |
| 1.9. How likely is the organism to be able to transfer from the pathway to a suitable habitat or host? | likely | high | The establishment of *O. gorbuscha* in new habitats seems to be very much dependent on the thermal conditions and access to, and availability of, suitable spawning habitat in rivers in the invasion area. Prevailing temperature regimes during incubation and the timing of appropriate fry migration for survival at sea are likely key to recruitment success. Any delay is likely to result in poor recruitment as the fry are small at seawater entry. Recent observations of spawning activity of *O. gorbuscha* in the rivers Ness, Spey and Dee (Scotland) in 2017, and recovery of deposited, fertilised and empty egg shells suggests that the species has successfully spawned eggs, and eggs have successfully incubated and hatched (C. Conroy, pers. comm. In Copp, 2017; B. Shaw, pers. obs.). In addition, pink salmon eggs that have been successfully hatched in *in situ* egg boxes in these rivers have been kept to the point where the egg sacs have been almost completely absorbed, suggesting these fish are about to become pink salmon smolts and thus complete the freshwater life stage of species (C. Conroy & B. Shaw, pers. obs.). The existence of successful spawning and hatching indicates the species has the potential to establish itself in GB river systems, particularly in Scotland where the habitat and environmental characteristics are similar to its home |

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| | | | range, but whether or not this will result in self-sustaining populations remains to be determined, as there is no record of juvenile *O. gorbuscha* being caught to date. Checking whether the newly hatched alevins grow to smolts and subsequently adults will likely require extensive electric fishing surveys and genetic studies. eDNA studies are not deemed appropriate because the adults and eggs are already present in the system, but can be used to determine presence of the species in rivers where they have not been captured or observed. |
| 1.10. Estimate the overall likelihood of entry into GB based on this pathway? | very likely | high | The species has exhibited high capacity for natural dispersion from the initial introductions to create a fishery in the White Sea area in Russia, and have a propensity for straying. The species has spread and established in rivers in northern Norway and Iceland over the last two decades. However, the very large increase in reported catches of *O. gorbuscha* in 2017 as far south as southern England, and the reported spawning of fish in the rivers Dee and Ness in Scotland, suggests a possible escalation of the species' spread. This proliferation may, however, be the result of a strong recruitment cohort in 2015 from reproduction in rivers where it has established, perhaps aided by a favourable match in environmental conditions suitable for successful reproduction of odd year stocks. It is unclear whether this represents a one-off event (e.g. due to particularly favourable conditions for spawning / early rearing), or an ongoing species range expansion. |
| Pathway name: | **3) Escape from aquaculture facilities.** | | |
| 1.3. Is entry along this pathway intentional (e.g. the organism is imported for trade) or accidental (the organism is a contaminant of imported goods)?<br><br>(If intentional, only answer questions 1.4, 1.9, 1.10, | accidental | low | There is no approved, or likely to be approved, introduction of *O. gorbuscha* into GB or north and northwest European waters for aquaculture purposes. Any direct introductions for aquaculture (and potentially stocking) will be deliberate illegal acts or contaminated |

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| 1.11) | | | supplies of Atlantic salmon, brown trout or rainbow trout for on-growing, although the latter is highly unlikely.<br><br>*O. gorbuscha* is not grown in significant numbers in fish farms globally, and most are produced for stocking, notably in the northern Gulf of Alaska and in Russia, the latter being the presumed source of *O. gorbuscha* in the GB assessment area. These have been intentionally introduced/stocked to create fisheries. |
| 1.4. How likely is it that large numbers of the organism will travel along this pathway from the point(s) of origin over the course of one year?<br><br>Subnote: In your comment discuss how likely the organism is to get onto the pathway in the first place. | very unlikely | high | Given the low potential for *O. gorbuscha* being introduced into GB or European waters (Q1.3) for aquaculture purposes, it is unlikely that the species will enter along this pathway, but should it occur the likelihood for dispersion around GB would be high if the species was able to establish in GB rivers. |
| 1.5. How likely is the organism to survive during passage along the pathway (excluding management practices that would kill the organism)?<br><br>Subnote: In your comment consider whether the organism could multiply along the pathway. | likely | high | If *O. gorbuscha* should escape from aquaculture facilities, or be stocked, there is a high likelihood it will establish given its systematic dispersal and establishment in rivers along the dispersion pathway from the White Sea through the north east Atlantic (see Figure 3), including in Norway, and the establishment of stocks introduced in the North American Great Lakes. Much will depend on the adaptive capacity of the species to establish, based on its origins and odd-even numbered year reproductive cycle versus climatic conditions in the UK. In addition, marine survival of smolts entering the estuary and coastal areas will likely depend on suitable feeding opportunities in this early life stage. |
| 1.6. How likely is the organism to survive existing management practices during passage along the pathway? | likely | high | Strict biosecurity regulations are in place to prevent importation and escape of non-native species from fish farms in the UK, and EU Regulation 2007/2008 should preclude the introduction of a new species for aquaculture (and thus stocking). |

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| | | | No specific management interventions are in place along the invasion pathway should the species escape or be introduced into open waters. |
| 1.7. How likely is the organism to enter GB undetected? | likely | high | There is considerable evidence that the species is present across Scotland and along the east coast of England as far as the Humber with the odd stray being found as far as Cornwall, the latter particularly in the past. It is highly likely the species has a wider distribution range, but has not been detected as yet because many anglers are unfamiliar with the species. The EA and SEPA are undertaking awareness campaigns and requesting anglers to report any pink salmon caught.<br><br>In addition, until fisheries surveys are conducted specifically to detect the presence of juvenile pink salmon, it is likely they will be overlooked, especially as the species often spawns in lower streams associated with estuarine waters (T. Quinn, pers. comm.). This is confirmed by K.W. Vollset (University of Bergen), who indicated that the fish were present in all of the rivers around Bergen following spawning. They seem to stay in fresh waters longer than expected (i.e. migrating out after their yolk was spent is the normal expectation), and seem to be waiting for some sort of cue. |
| 1.8. How likely is the organism to arrive during the months of the year most appropriate for establishment? | moderately likely<br>likely | high | Introductions into GB will depend on the life stage being produced and timing of 'introduction' into open waters. It is unclear whether juvenile fish will survive in GB rivers and reach the smolt life-stage but evidence from successful spawning in Scotland and establishment of the species in rivers in Norway and the North American Great Lakes suggests that establishment in the wild is likely if the species were introduced through this pathway. |
| 1.9. How likely is the organism to be able to transfer from the pathway to a suitable habitat or host? | moderately likely | high | The establishment of *O. gorbuscha* in new habitats seems to be very much dependent on the thermal conditions and |

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| | | | access to and availability of suitable spawning habitat in rivers within the invasion area. Recent observations of spawning activity of *O. gorbuscha* in the rivers Ness, Spey and Dee (Scotland) in 2017, and recovery of deposited, fertilised and empty egg shells suggests that the species has successfully spawned eggs, and eggs have successfully incubated and hatched (C. Conroy, pers. comm. in Copp, 2017). In addition, pink salmon eggs that have been successfully hatched in in situ egg boxes in these rivers have been kept to the point where the egg sacs have been almost completely absorbed, suggesting these fish are about to become pink salmon smolts and thus complete the freshwater life stage of the species (C. Conroy & B. Shaw, pers. obs.). The existence of successful spawning and hatching indicates the species has the potential to establish itself in GB river systems, particularly in Scotland where the habitat and environmental characteristics are similar to its home range, but whether or not this will result in self-sustaining populations remains to be determined as there is no record of juvenile *O. gorbuscha* being caught. |
| 1.10. Estimate the overall likelihood of entry into GB based on this pathway? | unlikely | very high | *O. gorbuscha* is not grown in significant numbers in fish farms, with perhaps the exception of Alaska, where 120 million harvested pink salmon are produced by fishery-enhancement hatcheries, particularly in the northern Gulf of Alaska. They were also produced in hatcheries in Russia for stocking but they are not produced for human food production.<br><br>*O. gorbuscha* is not reared in GB or northern and western Europe for food, stock enhancement or introduction purposes. Any importation and production, for whatever purpose, will have to comply with EU Council Regulation 708/2007 and require containment/quarantining in land-based units in the first instance. The likelihood of escape from such secure units would potentially be low, although |

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| | | | illegal importation and rearing of pink salmon is possible. |
| End of pathway assessment, repeat as necessary. | | | |
| 1.11. Estimate the overall likelihood of entry into GB based on all pathways (comment on the key issues that lead to this conclusion). | likely | high | The species has established self-sustaining populations outside its native range (the most convincing evidence thereof coming from the Great Lakes of North America, Russia, Norway and Iceland). Small numbers of fish have been caught in GB water since 1960, but recent observations of spawning activity of *O. gorbuscha* in the rivers Ness, Spey and Dee (Scotland) in 2017 suggest that the species has entered GB systems in large numbers. The large numbers of pink salmon observed in 2017 represents a proliferation of the entry into and potential establishment in GB rivers.<br><br>The most likely pathway is dispersal from previous introductions in the wider region, as already described. |

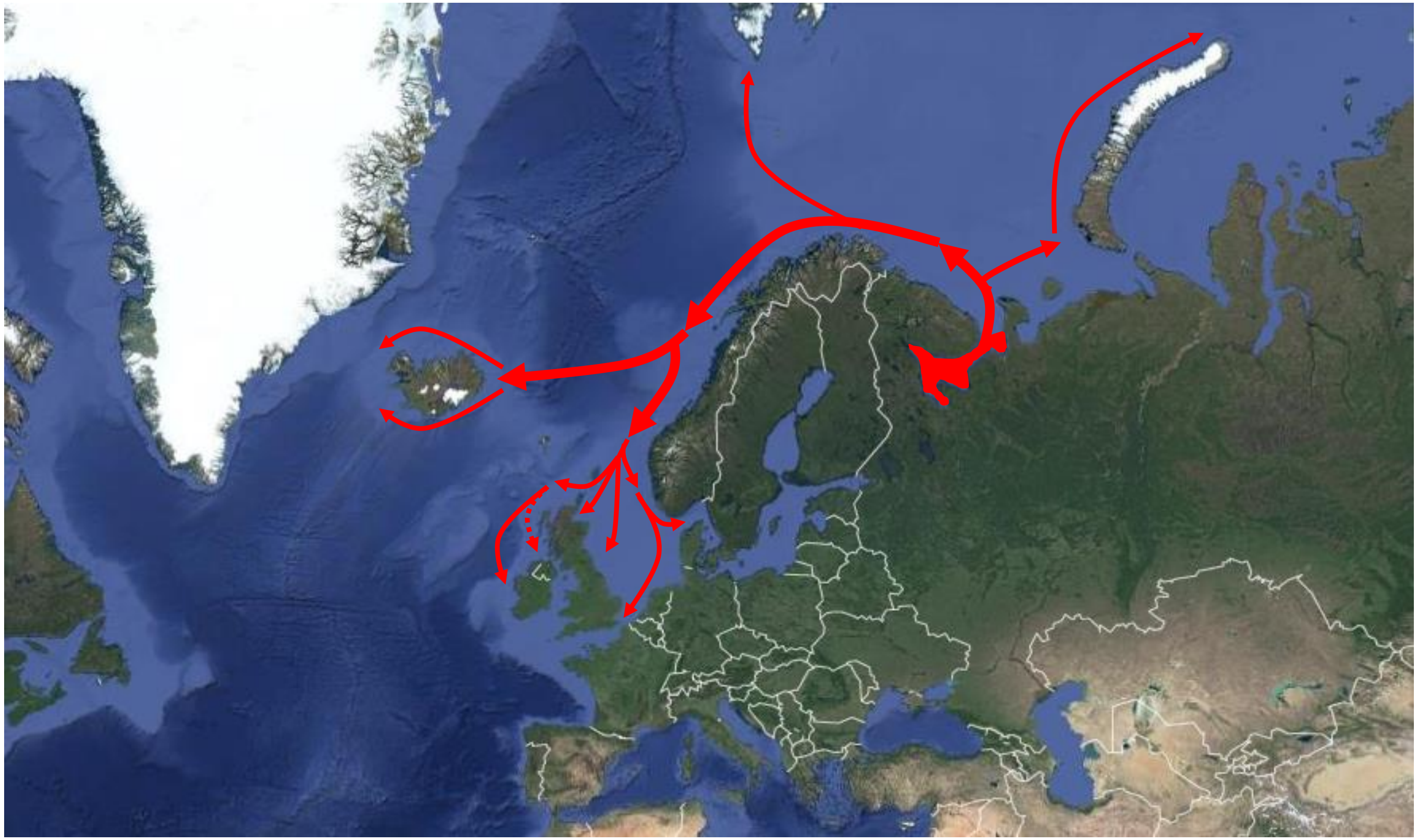

Figure 3. Potential invasion pathways of pink salmon in north and western Europe (Source: Colin Bean SNH meeting Edinburgh - 21 September 2017). The species originated in Russian commercial net fisheries before self-sustaining populations escaped to rivers in Finland, Norway, and the UK.

# PROBABILITY OF ESTABLISHMENT

Important instructions:

- For organisms which are already well established in GB, only complete questions 1.15 and 1.21 then move onto the spread section. If uncertain, check with the Non-native Species Secretariat.

| QUESTION | RESPONSE | CONFIDENCE | COMMENT |
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| 1.12. How likely is it that the organism will be able to establish in GB based on the similarity between climatic conditions in GB and the organism's current distribution? | likely | medium | *O. gorbuscha* is an anadromous species that requires access to steams for spawning and connectivity with the marine environment for on-growing to adult size. They also commonly spawn quite close to the ocean and indeed, intertidal spawning is not unusual in south-east Alaska.The species exhibits a short two-year life cycle during which they mature and reproduce. There are two reproductively isolated populations that spawn in alternate even and odd years, but the stock that appears to have established in the European waters is the odd-year stock that arises from the northern origins. The origins of this northern stock appear to have the most suitable climatic (temperature) match with northern European (including GB) river systems, but it is unclear whether the environmental characteristics to which this stock is adapted represents a closer match to environmental conditions in the recipient area than the even year stocks, or whether conditions experienced in northern Europe in 2015-2017 have contributed to the proliferation in GB in 2017. Nonetheless Dyagilev & Markevich (1979) suggested that *O. gorbuscha* from more southern populations begin to spawn too late in the original areas of introduction around the White Sea and eggs are lost as water temperatures in autumn are colder than those in their native habitat. This mismatch may not be the case in GB where winter temperatures are less severe and fish from these origins may survive and thrive, especially under predicted climate change scenarios. Such a scenario seems to be occurring in Norway, where pink salmon have been observed successfully |

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| | | | spawning in six rivers, but smolts were observed migrating the following spring in two of the rivers (Hesthagen & Sandlund, 2016). Furthermore, the widespread presence of juveniles in the rivers around Bergen in Norway (K.W. Vollset, University of Bergen), for example, suggests that they are able to establish and there may not be a phenotypical mismatch.The fact that individuals have spawned in the rivers Dee, Spey and Ness in 2017 suggests environmental conditions are suitable for reproduction, but whether these lead to recruitment to the stocks is unknown but may be determined if large numbers of fish return to these rivers, and others in the region, in 2019. It should be noted that pink salmon populations in their native range commonly fluctuate greatly in abundance (e.g. Heard 1978). The juveniles do not rear in rivers and so the dynamics are driven by survival at the egg to fry and marine stages without the freshwater periods than often buffer by compensation the recruitment in other salmonids. |
| 1.13. How likely is it that the organism will be able to establish in GB based on the similarity between other abiotic conditions in GB and the organism's current distribution? | likely | high | The species has already established self-sustaining populations outside its native range, notably in Russia, Norway, Iceland and the North American Great Lakes. The latter highlights the plasticity of the species to adapt to new environments, specifically establishing a land-locked population.<br><br>Recent evidence of successful spawning and grow out to smolt stages, in the rivers Ness and Spey (Scotland) in particular, indicates the potential to establish in river systems in GB, but whether or not this will result in self-sustaining populations remains to be determined. |
| 1.14. How likely is it that the organism will become established in protected conditions (in which the environment is artificially maintained, such as wildlife parks, glasshouses, aquaculture facilities, terraria, zoological gardens) in GB? | unlikely | very high | *O. gorbuscha* is grown in fish farms in the northern Gulf of Alaska and in Russia, predominantly for stocking. There is no reason why they cannot be successfully bred and grown in GB. This is effectively proven by successful hatching of eggs collected from redds in the River Ness in laboratory conditions (Bean, 2017). |

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| Subnote: gardens are not considered protected conditions | | | |
| 1.15. How widespread are habitats or species necessary for the survival, development and multiplication of the organism in GB? | widespread | Very high | *O. gorbuscha* is an anadromous species so requires connectivity between the sea and spawning streams. The habitat conditions for successful reproduction and recruitment appear to be similar to those of native GB salmonids so all rivers where these species currently reproduce or have reproduced in the past are likely to be suitable for establishment of *O. gorbuscha*. The species has been found in 18 rivers in Scotland and a number of rivers across England including rivers on the east coast of England as far south as the Humber, the Hampshire Avon and Frome on the south coast and the Duddon on the north-west coast in 2017. They have also successfully spawned in the Rivers Dee and Ness in 2017. These rivers, with the exception of the West Beck (River Hull), are typical salmonid rivers suggesting *O. gorbuscha* can exploit all rivers that support native migratory salmonids in GB, and possibly rivers that support native potadromous salmonid stocks (i.e. brown trout). |
| 1.16. If the organism requires another species for critical stages in its life cycle then how likely is the organism to become associated with such species in GB? | NA | very high | *O. gorbuscha* has no known dependence on any other species. |
| 1.17. How likely is it that establishment will occur despite competition from existing species in GB? | likely | medium | The life cycle of *O. gorbuscha* is somewhat asynchronous with that of native salmonid species in that adults enter the rivers in June-September and spawn over this time period. Spawning will thus be finished before *S. salar or S. trutta* begin spawning in late November – January, thus there is unlikely to be any competition for spawning sites or destruction of redds. ICES (2013) noted a lack of any evidence to suggest interactions with *S. salar* at the spawning grounds, although Ruggerone & Nielsen (2004) noted *O. gorbuscha* out-compete other salmonid species for spawning grounds and this could potentially impact on native salmonids if |

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| | | | they delay spawning migrations until later in the year.<br><br>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. Hatching takes up to 40 days depending on ambient water temperature at this time and emergence some weeks later. Fry migrate to sea shortly after emerging from the gravel, hence any impacts on the freshwater ecosystem are minimal. Consequently, there is unlikely to be much direct competition with juvenile Atlantic salmon or brown trout or other freshwater species, and if so it will be over a very short time period (ICES 2013). Nevertheless, the persistence of alevins/juveniles in the rivers around Bergen (Mo et al. 2018), suggests that small changes in the phenology of the species may increase the potential for some competition for resources, but this will likely be minimal. Furthermore, pink salmon have been observed to spawn successfully in six rivers, and smolts were observed migrating the following spring in two of the rivers (Hesthagen & Sandlund, 2016). Also, adult *O. gorbuscha* do not feed after entering fresh waters (Heard, 1991) so will not compete with large fish in the invaded river or predate on other species or food resources. |
| 1.18. How likely is it that establishment will occur despite predators, parasites or pathogens already present in GB? | likely | medium | *O. gorbuscha* will be exposed to similar predation threats, parasites and pathogens as native salmonids (Marty et al., 2010). There is no information on tolerances of pink salmon to parasites and pathogens already present in GB or predation by birds and mammals that typically affect native salmonids. Pathological examination of specimens from the 2017 by the Environment Agency (G Davies, pers. comm,) cohort yielded no specific parasites or pathogens of concern other than salmon lice and *Saprolegnia*. |
| 1.19. How likely is the organism to establish despite existing management practices in GB? | moderately likely | medium | There are no management practices directly targeting *O. gorbuscha* in GB. |

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| | likely | | There are also no management interventions in place should the species establish in open waters, although active fishing and culling of adults and raking of redds is being considered for GB. However, the costs of destroying redds appears expensive and culling of adults is unlikely to be successful given the limited capacity to catch fish efficiently by netting or angling. Trapping of adults at obstructions might improve capture but would be resource intensive.<br><br>Irrespective, unless the species is eradicated from the region the populations will be replenished from other self-reproducing stocks in the north-east Atlantic seaboard. |
| 1.20. How likely are management practices in GB to facilitate establishment? | very unlikely | high | There are no management practices directly targeting *O. gorbuscha* in GB. However, indirect management activities to improve longitudinal connectivity in GB rivers to enable free access for all migratory fish species in line with meeting EU Water Framework targets will likely facilitate the wider access of *O. gorbuscha* into GB rivers, especially to streams further upstream where they could potentially spawn. This is possible given the species is exhibiting tendencies to increase its upstream range in rivers in its native range, noted by studies on the MacKenzie river in Canada (CBC News https://t.co/PYcKFFI87h). Knowing how far pink salmon migrate upstream in GB rivers would be useful information to guide any potential management interventions. |
| 1.21. How likely is it that biological properties of the organism would allow it to survive eradication campaigns in GB? | moderately likely likely | medium | *O. gorbuscha* exhibits a migratory (anadromous) life cycle and seemingly has invaded many parts of the north Atlantic sea board of Europe. Once established in a few rivers it is likely the runs into GB will be replenished from other invaded rivers through natural dispersion. Eradication would have to be from the entire European invaded area which is unrealistic. |
| 1.22. How likely are the biological characteristics of the organism to facilitate its establishment? | moderately likely likely | medium | *O. gorbuscha* is a diadromous species that has the shortest life cycle for any salmonid. The species tend to return to natal rivers in the summer of its second year of life to spawn, although |

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| | | | considerable straying has been observed in the species (Ueda, 2012). Eggs hatch and alevins emerge from the gravels relatively quickly compared with other salmonid species because of the higher summer temperature during the incubation period. The juveniles spend relatively little time in fresh waters (a few days to a few months) before migrating to the sea for growing on to adult size (Heard, 1991; Quinn 2005, 2018 in press)). They return to spawn after approximately 18 months at sea. The adults typically lay a large number of eggs that are protected in redds and juveniles hatch and migrate to the sea quickly compared with other salmonid species. Their fast growing, early reproduction, large eggs that are protected in incubation, are all traits that would lead to successful establishment.<br><br>Recent anecdotal information (from fishers) for some rivers in both southern and northern Norway also indicate that there was a second run of *O. gorbuscha* migrating up river in September 2017, after the earlier arrivals had spawned (E. Thorstad, Norwegian Institute for Nature Research, pers. comm.: in Copp, 2017). This would also improve the capacity to establish and survive stressful periods, almost acting as an insurance for failure of early run fish to spawn.<br><br>Keefer & Caudill (2014) also noted that species *O. gorbuscha*, with a relative short life cycle, have 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). This higher straying rate will aid further spread of the species. |
| 1.23. How likely is the capacity to spread of the organism to facilitate its establishment? | moderately likely<br>likely | medium | *O. gorbuscha* is a highly migratory species that has exhibited considerable capacity to disperse from its original introduction in the White Sea in the 1980s-2003. Previously only a few specimens have been recorded in GB rivers and coastal fisheries, but an explosion in numbers has been recorded across northern Europe, including GB in 2017. The cause of this explosion is |

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| | | | unclear. |
| 1.24. How likely is the adaptability of the organism to facilitate its establishment? | likely | medium | The diadromous life cycle of *O. gorbuscha* and its capacity to adapt to new environments (i.e. establishment of a landlocked population in the Great Lakes of North America) suggest plasticity in the life history traits of the species. Consequently the species is likely to adapt to new environments available in GB rivers. This is illustrated by the large number of redds observed in, for example, the River Ness in 2017, indicating the capacity for the species to potentially establish in salmonid river systems. |
| 1.25. How likely is it that the organism could establish despite low genetic diversity in the founder population? | likely | High | The species has already established in north-east Atlantic rivers and the strong cohort of fish in 2017 suggests the species is capable of establishing a viable stock, although it is unknown if this establishment and further spread will be constrained by low genetic diversity of the founder population, although Gilk et al. (2004) found outbreeding depression in hybrids between spatially separated *O. gorbuscha*. However, the original stocking of many fish over many years may now have eliminated this potential bottle neck. |
| 1.26. Based on the history of invasion by this organism elsewhere in the world, how likely is to establish in GB? (If possible, specify the instances in the comments box.) | likely | high | The species has already established self-sustaining populations outside its native range, notably in Russia, Norway, Iceland and the North American Great Lakes. The latter highlights the plasticity of the species to adapt to new environments, specifically establishing a land-locked population. |
| 1.27. If the organism does not establish, then how likely is it that transient populations will continue to occur?<br><br>Subnote: Red-eared Terrapin, a species which cannot re-produce in GB but is established because of continual release, is an example of a transient species. | very likely | very high | *O. gorbuscha* has a migratory (anadromous) life cycle and it has invaded many parts of the north Atlantic seaboard of Europe, although evidence of establishment is currently absent in many invaded rivers. The species has, however, already established in several rivers in Norway and Iceland as well as local self-reproducing populations in the White Sea rivers in the Murmansk and Archangelsk regions of Russia where it was first introduced to establish a fishery. If the species does not establish in GB it is likely that dispersion and straying from these sources will maintain transient populations (Keefer & Caudill, 2014). |

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| | | | The strength of these populations will likely depend on the environmental conditions and will likely be greater in odd years to align with the strong 2017 influx of fish. It is unknown whether strong cohorts will be established in even years. |
| 1.28. Estimate the overall likelihood of establishment (mention any key issues in the comment box). | likely | High | The species has established self-sustaining populations outside its native range (the most convincing evidence thereof coming from the Great Lakes of North America, Russia, Norway and Iceland). Recent observations of spawning activity of *O. gorbuscha* in the rivers Ness, Spey and Dee (Scotland) in 2017, and recovery of deposited, fertilised and empty egg shells suggests that the species has successfully spawned and eggs incubated and hatched. This indicates that the species has the potential to establish in GB river systems, particularly in Scotland where the habitat and environmental characteristics are similar to its home range, but whether or not this will result in self-sustaining populations remains to be determined. Much will depend on whether the environmental conditions match the thermal requirements of stocks that breed in odd years, which appear to be the most prevalent breeding cohort currently found in the GB waters, and which have established self-sustaining populations in Norway. |

# PROBABILITY OF SPREAD

Important notes:

- Spread is defined as the expansion of the geographical distribution of a pest within an area.

| QUESTION | RESPONSE | CONFIDENCE | COMMENT |
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| 2.1. How important is the expected spread of this organism in GB by natural means? (Please list and comment on the mechanisms for natural spread.) | major | high | The species appears to originate from introductions of an odd-year cohort of *O. gorbuscha* to the White Sea basin, particularly a stocking event 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). The species is showing periodic explosions in abundance in synchrony with odd year reproductive bouts, a phenomenon typically found in the species because of its two-year reproductive cycle.<br><br>The species is spreading by natural dispersion from north to south in Scotland and England, along both the North Sea and Atlantic seaboards. There is no confirmed evidence of establishment in GB rivers. |
| 2.2. How important is the expected spread of this organism in GB by human assistance? (Please list and comment on the mechanisms for human-assisted spread.) | minimal | high | *O. gorbuscha* is spreading by natural dispersal and it is unlikely human assistance will exacerbate the spread, given the likely impact the species may have on traditional Atlantic salmon and sea trout fisheries. Managers and anglers will likely not want to see further deterioration of existing native migratory salmonid fisheries in GB. |

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| | | | Furthermore, conservation agencies and regulators will likely publicise the impacts of *O. gorbuscha* on existing fisheries and aquatic ecosystems and the need to avoid human transfer of eggs, juveniles or adult life stages.<br><br>The species is not considered important for commercial aquaculture in Europe and is not listed on Annex 4 under EU Regulation 207/2008 therefore will require community approval before it can be introduced in Europe for commercial aquaculture production. |
| 2.3. Within GB, how difficult would it be to contain the organism? | very difficult | high | The anadromous life cycle of the species and its rapid reproductive mode (2-year cycle) will make containment or control of the species virtually impossible. Any eradication would have to be across the north east Atlantic seaboard including from original source populations in the White Sea. Without such a large scale eradication programme the GB populations would likely be replenished from other established stocks. Containment in GB rivers would only be practical by destroying all redds each year and comment from the Ness and Beauly DSFB would suggest this would be intensive over a very short period and the practicalities of finding all redds is considered unachievable. |
| 2.4. Based on the answers to questions on the potential for establishment and spread in GB, define the area endangered by the organism. | All GB salmonid rivers, including those that previously supported migratory salmonids with the exception of those where physical barrier prevent access to upstream spawning areas. | medium | The species is spreading by natural dispersion from north to south in Scotland and England, along both the North Sea and Atlantic seaboards. There is evidence of successful spawning and hatching in the rivers Ness, Spey and Dee in Scotland and given time it is possible this could expand to all migratory salmonid rivers in GB. Given the uncertainty about successful recruitment to the adult stock from spawning in the River Ness, it is unclear whether this represents self-reproducing stocks or remains limited to dispersion from established stocks elsewhere in Europe. |
| 2.5. What proportion (%) of the area/habitat suitable for establishment (i.e. those parts of GB | 0-10 | medium | *O. gorbuscha* has been found in 18 rivers in Scotland and in a number of rivers on the east coast of England as far south |

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| were the species could establish), if any, has already been colonised by the organism? | | | as the Humber, the Hampshire Avon and Frome on the south coast and the Duddon on the north-west coast in 2017. They have also successfully spawned and grown to yolk absorption stage in the rivers Dee and Ness in 2017. Whilst this does not represent colonization per se, it highlights the extent of river systems exposed to potential colonization to date.<br><br>It is virtually impossible to assess how much suitable habitat could have already been occupied by pink salmon as there is no well-established monitoring programme and distribution is mostly based on opportunistic sightings of the fish in rivers and reported catches. |
| 2.6. What proportion (%) of the area/habitat suitable for establishment, if any, do you expect to have been invaded by the organism five years from now (including any current presence)? | 0-10 | low | Much will depend on whether the 2017 explosion is a one-off event or sign of future biennial proliferation of odd year stocks, and whether the species becomes established in GB rivers, notably in the rivers Ness and Dee. If the widespread prevalence and large numbers observed is a one-off event, then further spread may be limited to past recordings of occasional fish. If this large number of individuals signifies a rapid increase in abundance and dispersion then it is possible populations will establish in large areas of the current distribution range in Scotland and Northeast England. |
| 2.7. What other timeframe (in years) would be appropriate to estimate any significant further spread of the organism in Great Britain? (Please comment on why this timeframe is chosen.) | 10-20 | medium | The species has a strict two-year life cycle (Heard, 1991; Mecklenburg et al. 2002; Quinn 2005, 2018;) and at least 3-5 generations would be required to confirm both the species' capacity to adapt to the GB riverine conditions and establish viable populations within the current distribution range. This establishment would have to be confirmed by formal monitoring and assessment of the status of stocks. A further number of generations would be required to confirm spread into more southerly and west coast rivers. |
| 2.8. In this timeframe what proportion (%) of the | 10-33 | low | Given the lack of understanding behind the proliferation of |

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| endangered area/habitat (including any currently occupied areas/habitats) is likely to have been invaded by this organism? | | | the species in GB in 2017, it is difficult to estimate the proportion of habitat that will be occupied by *O. gorbuscha* in significant numbers over a number of generations. However, contingency plans should be put in place should further spread and escalation in the numbers of the species be observed in 2018 and beyond. |
| 2.9. Estimate the overall potential for future spread for this organism in Great Britain (using the comment box to indicate any key issues). | Moderately | medium | Unfortunately, it is difficult to determine the proportion of available habitat that has been occupied by *O. gorbuscha* in GB. The current distribution of *O. gorbuscha* in GB rivers is largely based on reported catches and sightings alone, there is currently no methodology to estimate how much suitable habitat could have already been occupied. The species is, however, prevalent in rivers from the north of Scotland down the east coast to the Humber and along the west coast as far as Cumbria. Numbers are lower the further south the fish have penetrated and are likely stray individuals.<br><br>As a consequence of the difficulties determining the actual distribution of *O. gorbuscha* it is also difficult to determine the potential future spread. Nevertheless, the species has systematically spread from the original introductions in the White Sea area by natural means since the 1980s (although the current stocks may be the outcome of later stockings at the beginning of the 21st Century. It has now established in Norwegian rivers and seems to be dispersing further south in greater numbers. If this dispersion continues it is possible all GB rivers supporting native migratory salmonids may be prone to invasion but it remains unknown if the 2017 escalation in numbers is a one-off event (e.g. due to particularly favourable conditions for spawning / early rearing) or an intensification of dispersal, perhaps reflecting warming trends in the North Atlantic. |

# PROBABILITY OF IMPACT

Important instructions:

- When assessing potential future impacts, climate change should not be taken into account. This is done in later questions at the end of the assessment.
- Where one type of impact may affect another (e.g. disease may also cause economic impact) the assessor should try to separate the effects (e.g. in this case note the economic impact of disease in the response and comments of the disease question, but do not include them in the economic section).
- Note questions 2.10-2.14 relate to economic impact and 2.15-2.21 to environmental impact. Each set of questions starts with the impact elsewhere in the world, then considers impacts in GB separating known impacts to date (i.e. past and current impacts) from potential future impacts. Key words are in bold for emphasis.

| **QUESTION** | **RESPONSE** | **CONFIDENCE** | **COMMENTS** |
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| 2.10. How great is the economic loss caused by the organism within its existing geographic range **excluding GB**, including the cost of any current management? | moderate | low | There is no known information on the economic losses resulting from the introduction and establishment of *O. gorbuscha* outside its native range, although there are recognised benefits accrued from the establishment of commercial and sport fisheries. |
| 2.11. How great is the economic cost of the organism **currently** in GB **excluding management** costs (include any past costs in your response)? | minimal | high | There is currently no known economic cost of the presence of *O. gorbuscha* in GB waters. Prior to 2017, the species was caught incidentally in rivers through the area but not considered an invasive species just an occasional migrant. Currently there is no reported impact on existing salmonid fisheries, loss of biodiversity or alteration of environmental conditions or ecosystem functioning as a result of the 2017 explosion in numbers of *O. gorbuscha* in GB waters. |
| 2.12. How great is the economic cost of the organism likely to be **in the future** in GB **excluding management** costs? | moderate | low | In the absence of any information on the severity of environmental, economic and social effects likely to be exerted by *O. gorbuscha* from other European countries it is difficult to estimate the economic costs to GB should the species establish in the main salmonid rivers. |

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| | | | No information about the economic cost of *O. gorbuscha* establishing in the Great Lakes of North America is available but the species supports a small commercial fishery that is of low value compared with the important coho salmon, Chinook salmon, rainbow and brown trout recreational fisheries. There appears to be no management intervention to control or eradicate the stocks in the Great Lakes of North America. Consultations are needed with European counterparts to identify any economic costs of the species invasion, especially those countries where the species has established. Any potential economic losses are likely to be associated with loss of Atlantic salmon and sea trout commercial and sport fishing opportunities if *O. gorbuscha* contributes to the deterioration of their stocks. There is also a need to consider the costs of protecting other fauna (e.g. Freshwater Pearl Mussel) if there is found to be an impact on native juvenile salmonids, or an impact on water quality from decaying carcasses. |
| 2.13. How great are the economic costs **associated with managing** this organism **currently** in GB (include any past costs in your response)? | minor | medium | Prior to 2017 there were no costs of managing the species in GB. Since then, any costs have been associated with determining whether the species is likely to establish in GB waters, investigating the likelihood of successful spawning and disturbance of redds to disrupt potential breeding success. The Ness and Beauly DSFB has indicated that the practicalities of disturbing all redds observed in the river in 2017 was prohibitive both in terms of cost and resources.<br><br>There are also additional costs associated with publicising issues associated with *O. gorbuscha* via traditional and social media outlets to alert anglers, and a review of the legislative framework for managing the |

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| | | | issue has been undertaken. |
| 2.14. How great are the economic costs **associated with managing** this organism likely to be **in the future** in GB? | moderate | low | In the absence of any major investment in control and eradication in any country, coupled with the unknown impacts of the species now and into the future, it is not possible to determine the economic costs of managing *O. gorbuscha* into the future. However, current fisheries management legislation is not geared to the management of pink salmon  and anglers who cannot legitimately fish for Atlantic salmon and sea trout may claim that they are fishing for pink salmon. This could, therefore lead to losses of Atlantic salmon due to what could be termed “illegal” fishing. Changes to the law may be required and there could be costs associated with that, as well as losses of native fish (C. Bean, pers. comm.). |
| 2.15. How important is environmental harm caused by the organism within its existing geographic range **excluding GB**? | moderate | low | There has been no specific evidence of any adverse impacts on the environment reported in European countries.<br><br>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. Given that spawning of *O. gorbuscha* finishes before the spawning of *S. salar* and *S. trutta* starts, it is unlikely such interactions will occur, although given the plasticity of *O. gorbuscha* they may shift their life cycle to adapt to the new environment and overlap in spawning areas and activities may occur in the future. Such a possible phenological shift may be occurring in Norway (Mo et al., 2018), whereby the juveniles are not migrating immediately to sea once the yolk sac is absorbed, and this may result in some competition for food resources. However, given the the diminutive size of pink salmon this makes them highly vulnerable to |

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| | | | predation in rivers following emergence and hence they are more likely to be a valuable food source for native fish and other biota than to compete for food. This needs further investigation. There is evidence that the biennial population cycle in planktivorous juvenile life stages of *O gorbuscha* can determine inter-annual variations in zooplankton and phytoplankton (Shiomoto et al., 1997; Pace et al., 1999), which could have implications for zoo- and phytoplankton in the invaded range. However, these effects were reported for freshwater ecosystems, and in European rivers it appears that *O. gorbuscha* fry migrate to sea shortly after emergence from the gravel. Thus, there is likely to be little competition for food with juvenile life stages of native fishes and the difference in size of emerging alevins against native salmonid fry and parr in the late summer period would suggest such competition is unlikely.<br><br>Adult *O. gorbuscha* do not feed in fresh water so will not compete for food or predate on native food resources whilst in the freshwater environment. No information on the distribution and feeding ecology of juvenile and sub-adult *O. gorbuscha* is available, and hence it is not possible to determine any potential competition with native species, predation impacts or impact on planktivorous or other food resources and trophic cascading in the marine environment, but this does not mean that such impacts are not likely.<br><br>There appears to be little evidence from Europe of adverse impacts caused by parasites and pathogens (Isehko et al. 2016), although *O. gorbuscha* is a potential vector of sea lice (Thrush et al., 2011), and thus may become a vector of lice and lead to increase loading on native salmonid fishes, but the high |

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| | | | prevalence of sea lice in association with coastal salmon aquaculture is likely to dissipate any dose response.<br><br>One possible impact of large numbers of *O. gorbuscha* invading European water is that they die soon after spawning and large numbers of carcasses may change the nutrient dynamics of headwater streams and fungi from carcasses may affect spawning native salmonids later in the year (Nelson & Reynolds 2015), as well as affecting nutrient-sensitive, high conservation-value species such as freshwater pearl mussel. In addition, there may be adverse impacts of dead and decaying fish carcasses on the 'angling experience' as well as attracting predators that may not have been present in large numbers before, e.g. otters, and vermin (even possibly mink) (K Whelan pers. comm.). |
| 2.16. How important is the impact of the organism on biodiversity (e.g. decline in native species, changes in native species communities, hybridisation) **currently** in GB (include any past impact in your response)? | moderate | low | As indicated above, there is no determined impact on biodiversity, although this does not mean that this will not evolve if the numbers of *O. gorbuscha* escalate in the future.<br>One issue that may arise is that spawning pink salmon may disturb nests of sea lamprey, *Petromyzon marinus*, which is a protected species in Europe (Armstrong et al. 2018). Sea lamprey spawning starts in late May-June, when river temperatures reach 15$^{o}$C (Beamish, 1980), and peaks when water temperature reaches 17-19 $^{o}$C (Hanson et al., 2016). Redds are constructed in areas similar to those used by spawning pink salmon. While lamprey eggs have a relatively short incubation period, they subsequently may remain in the gravel for 10-13 days before moving downstream as larvae to suitable juvenile holding habitat (Piavis, 1972).<br><br>One other period when there is likely to be competition with native fishes is when adult pink salmon are |

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| | | | creating and defending nests. Adult pink salmon may exclude fish from areas of river, or interfere with migration. Such interactions may affect freshwater pearl mussels *Margaritifera margaritifera* at the stage where the glochida attach to gills of Atlantic salmon and brown trout, thus compromising recruitment of pearl mussel. |
| 2.17. How important is the impact of the organism on biodiversity likely to be in the **future** in GB? | moderate | low | No available evidence. |
| 2.18. How important is alteration of ecosystem function (e.g. habitat change, nutrient cycling, trophic interactions), including losses to ecosystem services, caused by the organism **currently** in GB (include any past impact in your response)? | moderate | low | As indicated above, no documented changes have been recorded in ecosystem function in the invaded areas, although some influence on planktonic communities and possibly trophic cascading may occur if the species establishes in GB waters and produces large numbers of juveniles and adults in the marine environment. |
| 2.19. How important is alteration of ecosystem function (e.g. habitat change, nutrient cycling, trophic interactions), including losses to ecosystem services, caused by the organism likely to be in GB in the **future**? | moderate | low | No available evidence. |
| 2.20. How important is decline in conservation status (e.g. sites of nature conservation value, WFD classification) caused by the organism **currently** in GB? | moderate | low | The presence of *O. gorbuscha* does not currently appear to have any significant impact on conservation or ecological status in GB rivers, although this does not mean that impacts will not become apparent if the numbers of *O. gorbuscha* escalate in the future. |
| 2.21. How important is decline in conservation status (e.g. sites of nature conservation value, WFD classification) caused by the organism likely to be in the **future** in GB? | moderate | low | No available evidence to determine, but conservation status may be compromised should the numbers of *O. gorbuscha* escalate in the future. |
| 2.22. How important is it that genetic traits of the organism could be carried to other species, modifying | minimal | high | There is currently no evidence of hybridisation between *Salmo* and *Oncorhynchus* species, and Loginova & |

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| their genetic nature and making their economic, environmental or social effects more serious? | | | Krasnoperova (1982) suggested that natural hybridisation of *O. gorbuscha* and *Salmo salar* would not occur. Natural hybridization is unlikely mainly because the two species spawn at different times of the year so synchrony of mature reproductively active adults on the spawning grounds will not occur unless one of both species evolves a new strain or adapts to changing environmental conditions. |
| 2.23. How important is social, human health or other harm (not directly included in economic and environmental categories) caused by the organism within its existing geographic range? | moderate | low | Currently, there is no indication of any social or human health harm resulting from the presence of *O. gorbuscha* in the European risk assessment area. The most likely impact will be decline in the fisheries for native salmonids, which could have social impacts, especially in rural areas with high dependence on fisheries for livelihoods. There may also be adverse impacts of dead and decaying fish carcasses on the 'angling experience' as well as attracting predators that may not have been present in large numbers before, e.g. otters and vermin (even possibly mink) (K Whelan pers. comm.). |
| 2.24. How important is the impact of the organism as food, a host, a symbiont or a vector for other damaging organisms (e.g. diseases)? | minor | medium | There appears to be little evidence from Europe of adverse impacts caused by parasites and pathogens, although *O. gorbuscha* is a potential vector of sea lice. |
| 2.25. How important might other impacts not already covered by previous questions be resulting from introduction of the organism? (specify in the comment box) | NA | medium | |
| 2.26. How important are the expected impacts of the organism despite any natural control by other organisms, such as predators, parasites or pathogens that may already be present in GB? | moderate | medium | The presence of *O. gorbuscha* does not currently appear to have any significant impact on ecosystem functioning, biodiversity or conservation in GB rivers, although this must be treated with caution because the numbers of *O. gorbuscha* found in GB waters prior to |

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| | | | 2017 was very small and impact of the escalation in numbers in 2017 is yet to be determined. |
| 2.27. Indicate any parts of GB where economic, environmental and social impacts are particularly likely to occur (provide as much detail as possible). | See Figure 2 | medium | In the short term, the greatest impacts are likely to be in the parts of GB where the species has been found in large numbers following the proliferation in 2017. Until the impacts of this escalation are known it is difficult to determine whether the species will spread and establish in other parts of GB. |

| **RISK SUMMARIES** | | | |
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| | **RESPONSE** | **CONFIDENCE** | **COMMENT** |
| **Summarise Entry** | very likely | high | The species has established self-sustaining populations outside its native range (the most convincing evidence thereof coming from the Great Lakes of North America, Russia, Norway and Iceland). Small numbers of fish have been caught in GB water over the past 57 years, but recent observations of spawning activity of *O. gorbuscha* in the rivers Ness, Spey and Dee (Scotland) in 2017 suggests that the species has entered GB systems in larger numbers than ever before. The large numbers of *O. gorbuscha* observed in 2017 represents a proliferation of the entry into and potential establishment in GB rivers.<br><br>The most likely pathway is dispersal from previous introductions in the wider region, as already described. |
| **Summarise Establishment** | very likely | high | The species has established self-sustaining populations outside its native range (the most convincing evidence thereof coming from the Great Lakes of North America, Russia, Norway and Iceland). Recent observations of spawning activity of *O. gorbuscha* in the rivers Ness, Spey and Dee (Scotland) in 2017, and recovery of deposited, fertilised and empty egg shells suggests that the species has successfully spawned and eggs incubated and hatched, and the recovery of alevins with well absorbed yolk sacs suggests that some natural recruitment may have occurred but survival of these alevins is not known. This indicates the species has the potential to establish in GB river systems, particularly in Scotland where the habitat and environmental characteristics are similar to its home range, but whether or not this will result in self-sustaining populations remains to be determined. Much will depend on whether the environmental conditions match the thermal requirements of stocks that breed in odd years, which appear to be the most prevalent breeding cohort currently found in the GB waters, and which have established self-sustaining populations in Norway. |
| **Summarise Spread** | rapidly | high | Unfortunately, it is difficult to determine the proportion of available habitat that has been occupied by *O. gorbuscha* in GB. The current distribution of |

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| | | | pink salmon in GB rivers is largely based on reported catches and sightings alone, there is currently no methodology to estimate how much suitable habitat could have already been occupied. The species is, however, prevalent in rivers from the north of Scotland down the east coast to the Humber and along the west coast as far as Cumbria. Numbers are lower the further south the fish have penetrated and are likely stray individuals.<br><br>As a consequence of the difficulties determining the actual distribution of *O. gorbuscha*, it is also difficult to determine the potential future spread. Nevertheless, the species has systematically spread from the original introductions in the White Sea area and spread by natural means since the 1980s (although the current stocks may be the outcome of later stockings at the beginning of the 21st Century. It has now established in Norwegian rivers and seems to be dispersing further south in greater numbers. If this dispersion continues, it is possible all GB rivers supporting native migratory salmonids may be prone to invasion but it remains unknown if the 2017 escalation in numbers is a one-off event (e.g. due to particularly favourable conditions for spawning / early rearing) or an intensification of dispersal, perhaps reflecting warming trends in the North Atlantic. This is possible given the species is exhibiting tendencies to increase its upstream range in rivers in its native range, noted by studies on the MacKenzie river in Canada. |
| **Summarise Impact** | moderate | low | There is no specific evidence of any adverse impacts on the environment reported in European countries and given that spawning of *O. gorbuscha* finishes before the spawning of *S. salar* and *S. trutta* starts, it is unlikely such interactions will occur, although this needs further investigation, although see Forseth et al. (2017). Particular attention must be paid, however, if future invading pink salmon spawn later in the year because this might result in a spring emigration of pink salmon, which could increase the chances of subsequent survival at sea and increase likelihood of populations becoming established.<br><br>There is evidence that the biennial population cycle in planktivorous juvenile life stages of *O gorbuscha* can determine inter-annual variations in zooplankton and phytoplankton abundance but these effects were reported |

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| | | | for freshwater ecosystems, and in European rivers it appears that *O. gorbuscha* fry migrate to sea shortly after emergence from the gravel, thus there is likely to be little competition for food with juvenile life stages of native fishes.<br><br>Adult *O. gorbuscha* do not feed in fresh water so will unlikely compete for food or predate on native food resources whilst in the freshwater environment. No information on the distribution and feeding ecology of juvenile and sub-adult *O. gorbuscha* is available for the Atlantic Ocean, information that is critical to understand the impact of pink salmon during their marine life phase.<br><br>There appears to be little evidence from Europe of adverse impacts caused by parasites and pathogens.<br><br>One issue that may arise is that spawning pink salmon may disturb nests of sea lamprey, *Petromyzon marinus*, which spawn in late May-June. Their redds are constructed in areas similar to those used by spawning pink salmon. While lamprey eggs have a relatively short incubation period, they subsequently may remain in the gravel for 10-13 days before moving downstream as larvae to suitable juvenile holding habitat.<br><br>One other period when there is likely to be competition with native fishes is when adult pink salmon are creating and defending nests. Adult pink salmon may exclude fish from areas of river, or interfere with migration. Such interactions may affect freshwater pearl mussels at the stage where the glochida attach to gills of Atlantic salmon and brown trout, thus compromising recruitment of pearl mussel.<br><br>There is no known information on the economic losses resulting from the introduction and establishment of *O. gorbuscha* outside its native range, although there are recognised benefits accrued from the establishment of commercial and sport fisheries.<br><br>There is currently no known economic cost of the presence of the species in GB waters. Prior to 2017, the species was caught incidentally in rivers through the area but not considered an invasive species just an occasional migrant. Currently there is no reported impact on existing salmonid |

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| | | | fisheries, loss of biodiversity or alteration of environmental conditions or ecosystem functioning as a result of the 2017 explosion in numbers of fish un GB waters. |
| **Conclusion of the risk assessment** | moderate | medium | Information is lacking on the species' impacts and/or interactions with native salmonids. The potential for impacts exists, but it is currently impossible to estimate the magnitude and extent of any impacts based on the available information. Thus, at the current time, the impacts are estimated to be moderate, with moderate to-high confidence levels associated with the risks of Entry, Establishment and Spread.<br><br>The greatest concern is that if future invading pink salmon spawn later in the year then the current assessment would require a drastic re-evaluation, since this might result in a spring emigration of pink salmon, which would increase the chances of subsequent survival at sea and increase likelihood of populations becoming established.<br><br>Caution needs to be taken with the current risk assessment because it is based largely on occasional, often anecdotal, sightings of *O. gorbuscha* in GB waters and only recent establishment in Norway. The situation and outcomes may change rapidly if the recent proliferation results in establishment of the species in GB waters and the evidence base and impact may change rapidly thereafter. It is therefore recommended a systematic monitoring of all UK rivers in the known range of the species, particularly in Scotland, northern England and Ireland is carried out. This should include, where appropriate, redd counts, electric fishing for juveniles and adults, angling campaigns and eDNA analysis. Where possible the full extent of movement into river systems should be elucidated to determine potential impact on native species and wider aquatic biodiversity. |

Additional questions are on the following page ...

| ADDITIONAL QUESTIONS - CLIMATE CHANGE | | | |
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| 3.1. What aspects of climate change, if any, are most likely to affect the risk assessment for this organism? | Temperature Hydrological regimes | medium | *O. gorbuscha* is an anadromous species that requires access to streams for spawning, and connectivity with the marine environment for on-growing to adult size. There are two reproductively isolated populations that spawn in alternate even and odd years but the stock that appears to have established in the European waters is the odd-year stock that arises from the northern origins. The origins of this stock appear to have the most suitable climatic (temperature) match with northern European (including GB) river systems, but it is unclear whether the environmental characteristics to which this stock is adapted represents a closer match to environmental conditions in the recipient area than the even year stocks, or whether conditions experienced in northern Europe in 2015-2017 have contributed to the proliferation in GB in 2017. This escalation is possible because above average temperatures were reported to be critical to the survival of early releases in Russia, and elevated temperatures arising from climate change might well enhance the capacity of existing established populations to recruit lading to the increase in numbers and the risk of further spread to rivers elsewhere, including those in GB.<br><br>The forecasted changes (increased hydrological variability, elevated water temperatures) arising from climate change may enable improved recruitment of *O. gorbuscha*, although in more southern parts of GB this may not be case as the temperatures may be too high. By contrast, climate changes effects are predicted to be disadvantageous for native brown trout *Salmo trutta* and Atlantic salmon *Salmo salar* (Elliott & Elliott, 2010). |
| 3.2. What is the likely timeframe for such changes? | 10-20 years | medium | Much will depend on whether the 2017 explosion is a one-off event or sign of future biennial proliferation of odd year stocks and whether the evidence can be found to link the escalation with a shift in climate. |
| 3.3. What aspects of the risk assessment are most likely to change as a result of climate change? | Potential breeding cycles of odd and even year | low | The potential risks posed by the species under conditions of climate warming are most likely to be linked to the tolerances of the two odd-even year cohorts and their capacity to adapt to or be facilitated by the predicted changes in terms of ability to establish (successfully breed) in GB waters. |

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| | stocks | | Unfortunately because of lack of information related to cause and outcome of the escalation in numbers in 2017 it is difficult to isolate whether temperature change is a viable driver of recruitment dynamics (and establishment) in Europe, and by association in GB. |
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| **ADDITIONAL QUESTIONS - RESEARCH** | | | |
| 4.1. If there is any research that would significantly strengthen confidence in the risk assessment please summarise this here. | Competition<br>Hatching and survival to emigration in controlled conditions – artificial channel<br>Genetic finger printing to identify source and sink populations | low<br>medium<br>high<br>very high | There is a paucity of information about the basic ecological characteristics of *O. gorbuscha* in Europe or the GB about which to make informed decisions about whether and how the species will establish and spread within the region. To rectify this a number of studies are required in the first instance including:<br>• Systematic monitoring of all UK rivers in the known range of the species, particularly in Scotland, northern England and Ireland is carried out. This should include, where appropriate, redd counts, electric fishing for juveniles and adults, angling campaigns and eDNA. Where possible the full extent of movement into river systems should be elucidated to determine potential impact on native species and wider aquatic biodiversity.<br>• DNA studies to determine the origins of the current large numbers of *O. gorbuscha* in GB waters, particularly if there is an association with the established populations in Norway.<br>• Information on the marine ecology for the Atlantic Ocean would be very useful, and systematic comparison of stable isotope values of N and C with sea trout and Atlantic salmon would help understand the ecological interactions between species.<br>• Continued experimental work in controlled environments (e.g. flume tanks) to determine success rates of hatching, emergence and recruitment to the marine stocks of eggs spawned in GB waters.<br>• Determination of whether emergent alevins and fry would compete with young of the year *S. salar* and *S. trutta* if in coexistence. |

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| | | | • Determination of the ecosystem effects of replacement of native salmonids by *O. gorbuscha* on ecosystem services and ecosystem functioning, including whether loss of native species would impact on propagation of pearl mussel populations.<br>• Assessment of the social and economic impacts of loss or substitution of native salmonid fisheries by *O. gorbuscha* fisheries.<br>• Review of potential control and containment measures should *O. gorbuscha* escalate in GB waters. |

Please provide a reference list on the following page ...

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