An Economic Evaluation of the Impact of the Salmon Parasite *Gyrodactylus salaris* (Gs) Should it be Introduced into Scotland
Report to the Scottish Executive Environment and Rural Affairs Department
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An Economic Evaluation of the Impact of the Salmon Parasite Gyrodactylus salaris (Gs) Should it be Introduced into Scotland

Summary Report
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An Economic Evaluation of the Impact of the Salmon Parasite *Gyrodactylus salaris* (Gs) Should it be Introduced into Scotland: Summary Report

**Background**

*Gyrodactylus salaris* (Gs) is a freshwater external ecto-parasite that infects Atlantic salmon (*Salmo salar*) and a number of other salmonid species. The aims of the study reported here were to estimate the economic consequences of the introduction of Gs into Scotland, and to identify the costs of prevention, eradication and containment.

Gs is one of many salmonid infecting gyrodactylid species, which belong to the Monogenea, a larger group of relatively simple, soft bodied flatworms that are, primarily, fish parasites. At less than 1 mm in length, Gs infests the skin, fins and gills where its attachment and grazing activity can lead to host death through salt and water imbalances.

Gs is thought to have been introduced into Norway during the 1970s on salmon smolts from Sweden when Norwegian hatcheries were unable to meet the demands of the growing salmon industry in Norway. The parasite subsequently spread from the initial hatcheries to other hatchery sites and rivers and by the mid-1980s it was estimated that Gs had been responsible for the loss of an estimated 300 tonnes of Norwegian Atlantic salmon.

Estimates of the economic benefits from maintaining Scotland’s Gs free status or controlling its spread in the event of its introduction, and of the implicit policy costs are intended to inform the development of strategies to be deployed should an infestation be identified in Scotland. It is generally assumed that the parasite would be introduced to a single location initially, with rapid infection of a single river system (catchment) a most likely consequence. It has also been assumed that if no action is taken to prevent transfer of Gs to other locations then, eventually, it could become established throughout Scotland leading to the potential decimation of wild salmon populations.

The parasite is most likely to spread from infected areas in water or on fish. Legislative controls exist to prevent fish movements from such areas abroad, and powers are currently being sought to prevent movements within the UK in the event of an outbreak. This study examines the cost of measures aimed at limiting the remaining possibility of transfer on wet clothing, angling and boating equipment.

In addition, there is a planned response to implement agreed emergency control measures to contain an infection following its detection. Subsequently, it might be possible to treat the water source using rotenone, a plant extract used extensively throughout Norway although not currently approved for use in the UK. This compound is used to remove the entire fish fauna from a river system, thereby removing any potential hosts for Gs. Salmonid populations then re-establish either as a consequence of salmon returning to spawn or as a result of restocking programmes. Aluminium sulphate, a more expensive alternative which is currently under trial, destroys the parasite but not the host fish. However, unlike rotenone, it may persist in the environment for long periods, depending on the specific conditions of the water and sediment chemistry.

Currently, the most appropriate strategy for containment or eradication of Gs is determined by catchment size and a range of physical and ecological factors. Thus, eradication is likely to be both technically feasible and economically justified for small, isolated river catchments, or even in larger catchments especially if the disease is caught early and can be confined to smaller downstream tributaries that can be segregated using dams. However, a less favourable cost-benefit relationship is likely for eradication if the parasite becomes established throughout very large catchments such as the Ness, Lomond and probably the Spey with complex systems of tributaries and deep lochs, particularly given current technology and scientific understanding. The Expected Value\(^1\) of eradication could be lower than the costs, and a policy of containment may therefore be the favoured option on economic grounds. This forecast could change as technology advances.

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\(^1\) Expected Value considers the possibility of a control measure not being 100% effective. It is found by multiplying a policy measure’s economic benefits by the probability of the measure being successful. It would need to be calculated on a case-by-case basis.
The Economic Consequences of Gs Infestation throughout Scotland

Two key approaches have been used to evaluate economic consequences:

1) **Calculation of economic impact**
   
   Essentially, the change in national or regional income and employment after a change in circumstance.

2) **Calculation of the expected economic value**
   
   Specifically, the Net Economic Value, as a measure of individuals’ wellbeing, as reflected in their Willingness To Pay after a change in circumstance.

The prevalence of Gs throughout Scotland would destroy salmon angling. The economic impacts, and the changes in economic value following the loss of salmon angling are summarised in Table I.

### Table I. Summary of Economic Effects if Gs Became Widespread in Scotland

<table>
<thead>
<tr>
<th>Economic Impact</th>
<th>Net Economic Value Lost (£m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Salmon Angler Expenditure in Scotland Each Year (£m)</td>
<td>61.7</td>
</tr>
<tr>
<td>Expenditure Lost to the Scottish Economy Each Year (£m)</td>
<td>44.8</td>
</tr>
<tr>
<td>Lost Scottish Household Income Each Year (£m)</td>
<td>34.5</td>
</tr>
<tr>
<td>Lost Scottish Employment (FTE) Each Year</td>
<td>1,966</td>
</tr>
<tr>
<td></td>
<td>Annual</td>
</tr>
<tr>
<td></td>
<td>Capitalised²</td>
</tr>
<tr>
<td>Economic Rent</td>
<td>16.5</td>
</tr>
<tr>
<td></td>
<td>550.0</td>
</tr>
<tr>
<td>Consumers’ Surplus</td>
<td>2.5</td>
</tr>
<tr>
<td></td>
<td>83.1</td>
</tr>
<tr>
<td>Net Economic Value</td>
<td>19.0</td>
</tr>
<tr>
<td></td>
<td>633.1</td>
</tr>
</tbody>
</table>

The key figures are losses of £34.5m of income to households, 1,966 full time equivalent jobs (FTEs) to the Scottish economy, and £633m Net Economic Value lost.

Although in addition to salmon angling, salmon aquaculture could be seriously affected by Gs, effectively the economic impact of Gs in Scotland will be almost completely limited to the loss of angling. The argument for this forecast follows.

At one extreme, if, for instance, 50% of the hatchery/nursery sector had to close, there would be an estimated loss of some 150 FTEs with a reduction in local income of £2.5m. At a rough estimate, an additional £150m and around 2000 FTEs would be lost if 25% of the salmon farming (production and processing) sector closed in consequence. However, the industry could minimise such impacts if investment is made in biosecure hatcheries and nurseries.

Given the application of agreed containment strategies, the spread throughout the freshwater production sector, if it occurs, will be slow. The appearance of Gs would be an additional incentive to accelerate the current trend towards increased use of tank-based smolt units, which utilise recirculated water supplies for environmental control, reduced pollution and increased biosecurity, making spread even less likely. Production based around mesh cages in freshwater lochs, which cannot be made biosecure, will utilise the new biosecure capacity. The cost of making the entire freshwater phase biosecure is estimated to be £30-£40m. Thus, unless a Gs outbreak occurs in the near future, or spreads extremely rapidly, the economic logic suggests that it is likely that the economic impact of Gs in Scotland will be almost completely limited to the loss of salmon angling. Consequently, Table I summarises the main economic effects from Gs infestation in terms of angling only.

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² Annual values have been capitalised over an infinite time period. For a discussion of capitalisation used in this study, see Appendix 3 to the main report of ‘An Economic Evaluation of the Impact of the Salmon Parasite Gyrodactylus salaris (Gs) Should it be Introduced into Scotland’.

³ Other incentives might include production scale factors and constraints imposed through the implementation of the Water Framework Directive.
The Economic Costs and Benefits of Gs Policy Options

The Options
The benefits from successful Gs policy initiatives are the avoidance of the adverse economic consequences summarised in Table I. To evaluate the expected economic benefits of any specific strategy, it is necessary to estimate the probability that the strategy will be successful. This allows the calculation of Expected Value (defined above). Factors such as the biology of the parasite, current practices within the aquaculture and fisheries sectors, and the likely response of different stakeholders to possible policy measures have all been considered in the cost/benefit analysis.

Costs and benefits have been examined for the following policies:

1) Prevention
   Measures that potentially reduce the probability of Gs entry.

2) Eradication
   An eradication strategy might be possible if Gs reaches Scotland and infests a small river catchment (e.g. the River Luce in the south west). The strategy would have implementation costs, but would also generate economic benefits as the river recovers.

3) Containment
   Should Gs reach Scotland and it infests a large river catchment (e.g. the Spey in the North East) then it might be decided that eradication is not feasible on economic, political and/or legal\(^4\) grounds. However, a strategy of containment to protect the rest of Scotland from infestation might be appropriate. Such a containment policy might be either limited (Minimal Exclusion), focusing only on the greatest risk of Gs transfer, or it could involve the Total Exclusion of the public from the water.

4) Other Measures
   Initiatives that cannot properly be described as containment or eradication measures but which are essentially complementary to these strategic approaches.

Prevention
A strategy to prevent the entry of Gs into Scotland is expected to involve a programme of public education and promotion of responsible behaviour, backed up by the provision of necessary facilities (e.g. for the disinfection of small boats and angling equipment) at strategic locations such as ports. The total estimated cost of these measures (Table II.) is £6m, which is small in comparison with both the Net Economic Value of £633m (approximately 1%) and the 1,966 FTE jobs at risk.

Table II. Costs of Measures to Prevent Gs Entry (£)

<table>
<thead>
<tr>
<th>Action</th>
<th>Applicable Years</th>
<th>Annual Cost</th>
<th>Capitalised Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Publicity</td>
<td>All</td>
<td>156,100</td>
<td>5,151,300</td>
</tr>
<tr>
<td>Disinfection Equipment</td>
<td>1</td>
<td>66,000</td>
<td>66,000</td>
</tr>
<tr>
<td>Maintenance</td>
<td>All</td>
<td>20,000</td>
<td>660,000</td>
</tr>
<tr>
<td>Disinfectant</td>
<td>All</td>
<td>5,000</td>
<td>165,000</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td><strong>247,100</strong></td>
<td><strong>6,042,300</strong></td>
</tr>
</tbody>
</table>

Thus, on the basis of the Net Economic Value alone, a long-term reduction in the likelihood of transmission of 1% is all that would be necessary to justify these measures.

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\(^4\) There are possible conflicts with both domestic and European law with respect to adverse effects of rotenone or aluminum sulphate (the chemical agents used) on protected species or purity of water used by distilleries, respectively.
Eradication: The River Luce case study

The Luce is a small river in South West Scotland with no aquacultural activity. A loss of 600 angler days would follow if it became infected, with a direct economic impact of £12,500 in lost local income. However, overall, there would be a positive economic impact of eradication because the cost of this is put at around £550,000, with a labour bill of £166,000. During the process of river treatment, enhanced local employment prospects and raised incomes would be expected before a return to the status quo.

In contrast to those calculations of a positive economic impact, there is a pronounced loss of Net Economic Value associated with Economic Rents and Consumers’ Surplus. There is a clear benefit if this value can be regained by eradication. The economic costs and benefits of eradication relative to the value of containment are shown in Table III for rotenone and in Table IV for aluminium sulphate.

Table III. Costs and Benefits of Treatment with Rotenone (£)

<table>
<thead>
<tr>
<th>Element</th>
<th>Applicable Year</th>
<th>Annual Cost</th>
<th>Present Value</th>
<th>Element</th>
<th>Applicable Years</th>
<th>Annual</th>
<th>Present Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rotenone Treatment</td>
<td>1</td>
<td>676,620</td>
<td>713,609</td>
<td>Salmon Rents</td>
<td>11 to end</td>
<td>22,879</td>
<td>561,791</td>
</tr>
<tr>
<td>Sea Trout Rents</td>
<td>1 to 10</td>
<td>5,000</td>
<td>42,651</td>
<td>Salmon Consumer’s Surplus</td>
<td>11 to end</td>
<td>1,266</td>
<td>31,087</td>
</tr>
<tr>
<td>Sea Trout Consumer’s Surplus</td>
<td>1 to 10</td>
<td>1,000</td>
<td>8,530</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sub-Total</td>
<td></td>
<td></td>
<td>592,878</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total Cost</td>
<td></td>
<td>764,790</td>
<td></td>
<td>Total Benefit</td>
<td></td>
<td>2,242,878</td>
<td></td>
</tr>
<tr>
<td>Benefit-Cost</td>
<td></td>
<td>1,478,087</td>
<td></td>
<td>Benefit/Cost Ratio</td>
<td></td>
<td>2.93</td>
<td></td>
</tr>
</tbody>
</table>

Acting alone, both rotenone and Gs will eradicate salmon stocks. Hence, the cost of the temporary loss of salmon following rotenone treatment is not attributable to the chemical because eradication is a consequence of infection regardless of its use. The costs of rotenone are, therefore, restricted to treatment costs, and also to mortality of sea trout (which would not occur in the absence of rotenone as Gs infection is not fatal in this species). The benefit of rotenone is re-establishment of the salmon population in about 10 years following treatment, and the consequent shortening of the containment period.

The analysis summarised in Table III clearly shows that the benefit of eradication by rotenone exceeds the benefits of containment alone, even if the potential benefits from removal of the transmission risk are ignored. The alternative treatment by aluminium sulphate, although more costly and labour intensive, has the major advantage of not being fatal to fish, so stocks will recover faster and angling can be resumed earlier.

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5 Economic Rent is e.g. anglers’ payments for access to private recreational fisheries. Consumers’ Surplus is the difference between what individuals (e.g. anglers) are willing to pay and what they are actually required to pay in the market place (their expenditure). See Sections 4.2 and 9 of the main report.

6 Best estimate derived from analysis of containment costs on the River Spey.
Table IV. Costs and Benefits of Treatment with Aluminium Sulphate (£)

<table>
<thead>
<tr>
<th>COSTS</th>
<th>BENEFITS</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Element</strong></td>
<td><strong>Applicable Year</strong></td>
</tr>
<tr>
<td>AIS Treatment</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>Total Cost</td>
<td></td>
</tr>
<tr>
<td>Benefit-Cost</td>
<td></td>
</tr>
</tbody>
</table>

In this case again, the benefits of eradication exceed those of containment.

On the basis of the benefit/cost ratio, rotenone is the preferred treatment for the Luce. However, for a salmon river larger and/or more productive than the Luce, but for which eradication is still feasible, aluminium sulphate treatment could be judged economically more advantageous, given the more rapid resumption of angling. It is difficult to generalise. The judgement would depend on many factors, including economies of scale effects, and would have to be made for each individual river.

**Containment: The River Spey case study**

The Spey is a much larger and more complex river system, providing habitats for a number of vulnerable species. Aquaculture in the area, almost wholly for recreational purposes, is incorporated into the economic impact assessment of Gs on angling.

In the event that it is considered that eradication is not feasible on economic, political, and/or legal grounds, the economic impact of Gs infection depends on the containment policies pursued, together with, since containment is not time limited, the period taken for economic recovery and the re-employment of those who lost their jobs.

Two containment policies were examined:

- Minimal Exclusion where only transport of fish and ‘water’ are banned, and
- Total Exclusion where all activities (except water for cooling in distilleries) are banned.

Operational difficulties prevented exploration of policies involving partial exclusions.

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7 It may be possible to catch and separately treat some fish prior to the eradication exercise, subsequently returning them so as to re-build stocks sooner. The economics of this would depend on surviving stock densities and individual river characteristics

8 In practice it is often necessary to use some rotenone in areas where the use of AIS is impractical
Table V shows the economic impact of an infection and its containment locally and nationally. Table VI shows the relative costs of the Minimal and Total Exclusion schemes, where the costs to the groups affected by Total Exclusion are assessed by their estimated Net Economic Value.

Minimal Exclusion incorporates a pass scheme to ensure disinfection of all boats and equipment when they leave the area, which, along with the ban on fish movement, should virtually eliminate the possibility of Gs transfer. The scheme’s running cost was found to be surprisingly small in the order of £175,000 per annum. In addition, the Minimal Exclusion policy does generate some FTEs in surveillance and in publicity.

<table>
<thead>
<tr>
<th></th>
<th>Minimal</th>
<th>Total Exclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Income (£)</td>
<td>FTEs</td>
</tr>
<tr>
<td><strong>Scotland</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other Angling</td>
<td>305,000</td>
<td>19</td>
</tr>
<tr>
<td>Other Recreation</td>
<td>250,000</td>
<td>15</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>555,000</td>
<td>34</td>
</tr>
<tr>
<td><strong>Local</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Water Sports</td>
<td>-100,000</td>
<td>-1</td>
</tr>
<tr>
<td>Other Angling</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Other Recreation</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Less Containment</td>
<td>-100,000</td>
<td>-1</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>-100,000</td>
<td>-1</td>
</tr>
</tbody>
</table>

Total Exclusion has a more dramatic effect because it stops all angling and water sports. It would also affect the attractiveness of the area for the one million tourists who visit the Cairngorm National Park and lower Spey each year. A conservative estimate of the effect of the additional constraints on the local area is over £1.75m in income and 106 FTEs. The impact on Scotland as a whole is much less because most users would simply shift their activities to somewhere else in Scotland.

<table>
<thead>
<tr>
<th></th>
<th>Minimal per Annum</th>
<th>Capitalised</th>
<th>Total Exclusion per annum</th>
<th>Capitalised</th>
</tr>
</thead>
<tbody>
<tr>
<td>Disinfection</td>
<td>75,000</td>
<td>2,500,000</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Security</td>
<td>0</td>
<td>0</td>
<td>250,000</td>
<td>8,250,000</td>
</tr>
<tr>
<td>Publicity</td>
<td>100,000</td>
<td>3,308,000</td>
<td>100,000</td>
<td>3,308,000</td>
</tr>
<tr>
<td>Other Angling</td>
<td>0</td>
<td>0</td>
<td>180,026</td>
<td>5,940,864</td>
</tr>
<tr>
<td>Other Groups</td>
<td>0</td>
<td>0</td>
<td>725,670</td>
<td>23,947,110</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>175,000</td>
<td>5,808,000</td>
<td>1,255,696</td>
<td>41,445,974</td>
</tr>
</tbody>
</table>

A containment policy’s costs can be justified by the measure’s reduction in the risk of spread of Gs to other rivers across Scotland with the loss of £633m Net Economic Value. Thus, if Minimal Exclusion reduces the risk of transmission by at least 0.91% it could be justified (the capitalised policy cost of £5.8m as a percentage of £633m). If Total Exclusion reduces the risk of transmission by at least 6.5% it could be justified (capitalised policy cost of £41.4m as a percentage of £633m).

Total Exclusion affects large numbers of other water users. Therefore, despite the very high value of salmon angling, in choosing the Total Exclusion policy over the Minimal Exclusion policy two conditions need to be considered:

a) In the event of Gs infecting a catchment there will be a risk of its spread to other rivers. Ideally, there should be evidence that the probability of transmission in the absence of any policy is high, estimated to be 6.5% or over.

b) The difference between the lowest risks that justify Minimal or Total Exclusions is 5.6%. Therefore, in choosing between the two policies, ideally there needs to be evidence that Total Exclusion reduces the risk of spread by 5.6% more than the risk reduction due to Minimal Exclusion.
Unfortunately, information on transmission probabilities is not currently available. It must be emphasised that catchments vary in other-user intensities and in physical characteristics. Each river system will need to be examined individually before a decision on the most appropriate scheme can be made.

Other Measures
The study looked at other measures that might be undertaken immediately, or possibly on first notification of infection within the UK, notably:

- Gene-banking and,
- Increased surveillance.

Gene-banking is the precautionary assembly of fish populations before Gs infestation (or any other potentially comparable event catastrophic to fish). The principal purpose of gene-banking is to enable re-establishment of natural populations native to specific rivers following successful eradication of Gs. Currently, there are no live fish gene-banks in the UK, and their establishment is both lengthy and costly.

A gene-bank accommodating a sample of 20 rivers would have a set-up cost of £16m, with a running cost of £1.2m per annum. This gives a total capitalised cost of £56m. There are over 380 salmon rivers in Scotland, so the cost of comprehensive gene-banking would be prohibitive. Further, given that rivers where eradication is likely to be successful are relatively small (the Luce, for instance), the chance of it being included in a limited gene-bank will be low. In addition, the value of re-instating salmon quickly in a small river attracting very few anglers will also be low.

**Surveillance** in the current programme involves sampling 226 sites annually (215 salmon or rainbow trout farms, and 11 rivers on a rolling system of 55 sites over five years). The implications of increasing surveillance to around 800 sites, including 385 rivers were examined. The total cost of the new regime would be £522,000 – an increase of £329,000 per annum. The capitalised cost would be £10.97m.

Surveillance has no value if the other precautionary measures succeed. In the event of failure, a value is generated where surveillance limits the spread of Gs from one river to the next. A value is also generated if surveillance allows the parasite to be confined and then eradicated within a section of a river system. If increased surveillance and early detection prevented spread, say from the River Findhorn to the Spey system, then it would have saved a system with an estimated capital value of £54.25m. It is difficult to justify extra surveillance if the probability of Gs entry is very low after the suggested precautions have been taken. However, if Gs is detected in Scotland (or the UK), transmission probabilities will have increased, the Expected Value of surveillance will increase correspondingly, and additional surveillance might be economically justified.

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* See Section 10.4 of the main report
Conclusions

1) The criteria used in this study suggest that should the Scottish Executive take no action to prevent the spread of Gs, Scotland could lose £34.5m of annual household income, 1966 full-time equivalent jobs and a decrease in Net Economic Value, capitalised at £633m.

2) Aquaculture is not as likely to be seriously affected because of the incentive for, and ability of the commercial organisations involved to protect themselves.

3) The probability of Gs entering the UK could be reduced considerably by the provision of disinfection stations at ports, and by extensive publicity identifying the danger of the parasite. The cost of these measures is put at a capitalised value of £6m.

4) On entry of Gs into a river system, the appropriate eradication/containment policy is wholly dependent upon the biological and physical characteristics of the river:

   I. For a small river, eradication is likely to be preferred on economic grounds to long-term containment. If the salmon catch is relatively large, it is likely that, despite the increased cost, aluminium sulphate might be preferred to rotenone because salmon angling can be resumed earlier.\textsuperscript{10}

   II. If the river system is large and complex, such as the Tay, Spey or Ness, there may be more technical, legal and political obstacles\textsuperscript{11} and the economic justification for eradication more uncertain. Further economic analysis of a clearly defined eradication plan in the largest systems is necessary in order to identify the conditions necessary for eradication to become appropriate.

5) In the Spey case study on containment, transmission probabilities were identified as a key factor in selecting between Minimal and Total Exclusion strategies. Transmission probabilities are influenced by the number of water sports-persons and visitors. The Total Exclusion strategy becomes more economically attractive with fewer users.

6) Further information in three areas would be useful for policy formulation:

   I. Transmission probabilities and the factors affecting them,

   II. The relationship between river geography and the potential for Gs eradication,

   III. The uses made of rivers in Scotland.

\textsuperscript{10} Although experience from Norway suggests that treatment with aluminium sulphate also requires the use of some rotenone to deal with Gs in the more inaccessible parts of the catchment.

\textsuperscript{11} See also footnote 3. Large complex catchments are more likely to encompass protected areas (e.g. SSSI or SAC) or industrial abstractions such that the likelihood of legal objections increases with river length.