PROJECT REPORT SARF 022

BIODIVERSITY IMPLICATIONS OF FARMING NOVEL AQUACULTURE SPECIES IN SCOTLAND

FINAL REPORT

PREPARED FOR SCOTTISH AQUACULTURE RESEARCH FORUM (SARF)

BY

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BIODIVERSITY IMPLICATIONS OF FARMING

NOVEL AQUACULTURE SPECIES IN SCOTLAND

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1. BACKGROUND TO THE APPROACH ADOPTED

1.1 Species and Situations Considered

This report views the protection of biodiversity in a broad context, ranging from protecting genetic diversity, through species and population diversity to the protection of habitat diversity.

We define novel species as those that have not been previously farmed on a commercial scale in Scotland. The study includes all potential commercial species (algae, invertebrates and fish). Native species are those that occur naturally in an area (in this case Scotland) and whose dispersal has occurred independently of human translocation (Manchester and Bullock, 2000). The principles of this study could be applied to non-native species, but it seems unlikely that mariculture developments for non-native species would obtain the necessary licences.

This study is primarily aimed at marine species, but could be adapted to cover freshwater species.

Whilst aimed at a Scottish audience the approach should be adaptable to other temperate countries. With some modifications to the weightings it could also be used in tropical mariculture.

1.2 New Mariculture Species

Novel mariculture species pose a challenge for those responsible for protecting the marine environment and biodiversity. They offer the potential of replacing over-exploited wild stocks, but could also affect biodiversity. The potential biodiversity impacts we have identified for novel species are essentially the same as for currently farmed species. The main difference is that ecological data (including diseases and parasites) and factors relating to their mariculture are usually more poorly known for the novel species. This means that any application to farm novel marine species requires more careful scrutiny to ensure that any environmental impacts are minimised.

Mariculture can provide much needed employment in remote areas where traditional employment is declining. Balancing the conflicting demands of economic growth and environmental protection in Scotland is a difficult task. The aim of this study is to provide a rational framework for assessing the risk to biodiversity of farming novel marine species.

A recent paper analysed potential finfish aquaculture species for the French Atlantic, English Channel and North Sea coast (Quéméner et al, 2002). The authors produced a ranked list of 27 species, the majority of which would be new species for Scottish aquaculture. Species in the top ten included albacore tuna, tope, anglerfish, bonito, hake and ling. Other mariculture species being considered include lemon sole, lumpsucker, sea urchins and abalones (Anon, 2005).

There is a need for a common methodology to assess the suitability of candidate mariculture species from an environmental perspective, including their impacts on biodiversity. Although the present study focuses on biodiversity issues, these cover the majority of environmental issues raised by marine aquaculture.

2. OBJECTIVES

The main aim of this study was to provide a common framework that the aquaculture industry may use to assess the possible risk to biodiversity of introducing a novel species. There is no suggestion that assessing this risk will be rapid, just that there could be a common framework within which to assess risk.

In particular, we aimed to produce a spreadsheet that will allow the relative risk of each species to be assessed.

Mariculturalists may also use the spreadsheet approach to assess the potential reduction in risk to biodiversity if additional mitigation measures are introduced.

For a particular proposal the approach may be used to highlight those issues where there is uncertainty and more information is required.

3. METHODS

The focus of the study was to produce a spreadsheet that would be simple to use. Relevant scientific literature was examined to provide a list of the mariculture issues related to the biodiversity aspects of farming novel species. Experts in aquaculture and marine biology helped us to identify the full range of issues and assess their relative importance.

3.1 Experts who provided inputs during the study

Dr Keith Hiscock of MarLIN (Marine Biological Association, Plymouth) acted as an internal advisor to Aquatonics Ltd during the study.

The external experts that contributed to the study were all based in Scotland and had a particular interest in aquaculture:

Ms Dawn Bache, Mariculture Officer, Marine Conservation Society, Edinburgh.

Dr Kenneth Black, Head of Ecology Department, Scottish Association for Marine Sciences, Dunstaffnage Marine Laboratory, Oban.

Dr Teresa Fernandes, Reader, School of Life Sciences, Napier University, Edinburgh.

Dr Clare Greathead, Biological Oceanographer, Fisheries Research Services, Marine Laboratory, Aberdeen.

The main regulatory bodies (Scottish Environmental Protection Agency and Scottish Natural Heritage) were asked if they would be willing to be involved but declined due to pressure of work for their staff.

3.2 Work Schedule

The study commenced in early January 2006 and lasted for seven months. The sequence of work during the study was:

1. Obtain relevant literature. Consult with Dr Keith Hiscock & other experts;
2. Produce a list of issues related to novel species that may affect biodiversity;
3. Assess scale of each issue (ie local regional, national or international);
4. Provide a weighting for each issue, using four external experts;
5. Produce an Excel spreadsheet to allow people to calculate an Index Score for each novel species;
6. Obtain feedback from SARF and its members;
7. Amend spreadsheet in the light of comments from SARF and its members; and
8. Produce guidance on the suggested scoring for each of the issues identified.

3.2.1 Obtaining Relevant Literature and Consultations with Experts

We consulted a wide range of reports and scientific papers that examined the impacts of aquaculture on the environment. These included reviews of the impacts of aquaculture (Black, 2001, Scottish Office, 2002), impacts of aquaculture on biodiversity (Beveridge et al, 1994; Beardmore et al, 1997; Beveridge, 2001), seaweed culture (Phillips, 1990), shellfish culture (Kaiser, 2001), risk assessment of non-native species in the UK (DEFRA, 2005), genetic impacts of aquaculture (Kapuscinski & Brister, 2001; Youngson et al, 2001; Myhr & Dalmo, 2005), assimilative capacity (Davies & Rae, 2003; SEPA 2004a), policy and management documents (Food and Agricultural Organisation, 2001; Commission of the European Communities, 2002; Scottish Natural Heritage, 2002; Scottish Executive, 2002 & 2003; ICES, 2005; SEPA, 2004a, 2004b & 2005) and the industry's Code of Good Practice for Finfish Aquaculture (Scottish Salmon Producers' Organisation et al, 2006).

Ancillary literature, such as the incidence of harmful algal blooms in Scottish waters (Tett and Edwards, 2002), the identification of risks from non-native freshwater fish (Copp et al, 2005) and the impacts of all types of non-native species on biodiversity in the UK (Manchester and Bullock, 2000) were also examined.

We also consulted with the five experts (one internal and four external) on the team to produce a full list of issues relating to impacts on biodiversity due to mariculture of novel species.

It became clear during this exercise that the main problem with identifying potential impacts of novel species on biodiversity was not that they present new issues, but simply that we rarely have enough information available to make detailed predictions about their impacts on biodiversity.

3.2.2 List of Issues

A total of 21 issues relating to potential biodiversity impacts of farming novel species were identified during the study. These are listed below and explanatory notes on each are provided in Section 4:

1. Availability and sustainability of food;
2. Availability and sustainability of wild broodstock (eggs, larvae, juveniles or adults);
3. Introduction of genetically modified organisms (GMOs), either as target species or in food;
4. Genetic intergradation between wild stock and cultivated stock;
5. Escape of fertilised eggs, juveniles and adults;
6. Competition between escaped non-native species and native species;
7. 'Collateral damage' - escapees sought as food by humans, leading to habitat disturbance;
8. Introduction of veterinary medicines;
9. Reduced water quality due to excretion and respiration;
10. Reduced water quality due to nutrients released and the BOD and COD of food, faeces and pseudo-faeces whilst in the water column;
11. Reduced sediment quality due to food, faeces and pseudo-faeces falling to the seabed;
12. Accidental importation of other species with the target species;
13. Transfer of diseases or parasites from the novel species to local wild or farmed species;
14. Use of antifoulants and other biocides on cages and other structures;
15. Loss of coastal habitats (such as wetlands) due to production and ancillary facilities;
16. Physical changes to habitat due to aquaculture facilities (eg suspended cultivation of bivalves);
17. Physical smothering of important habitats;
18. Disturbance due to aquaculture operations including harvesting;
19. Attraction of predators to the fish/shellfish farm and control measures such as scaring/culling;
20. Litter and debris from farms e.g. plastic bags and wrapping; and
21. Positive effects, such as plankton & nutrient removal by shellfish farms.

3.2.3 Assess the Scale of Each Issue

The scale (or geographical extent) of each issue was assessed by Aquatonics Ltd. The geographical extent was assigned to one or more of the following categories:

Local	Within the water body (eg sea loch) or for coastal sites within an agreed distance (we suggest 10 kms)
Regional	We suggest the SEPA Regions (West, North and East)
National	Scotland
International	Outside Scotland

The scale for each issue is summarised in Table 1, which should be considered a preliminary assessment.

3.2.4 Weighting of Each Issue

The four external experts were asked to provide a weighting for each issue in the range 1-10. They were asked to not contact each other regarding the weightings as we wanted to see whether their opinions coincided. Of the 21 issues there was good agreement on 13, but for 8 issues there were large ranges in weightings. The expert(s) with outliers were asked if they wanted to reconsider their weightings after seeing those from the others. In most cases there were revisions towards the mean, but in some cases the weighting was unchanged.

The revised weightings given by the experts are shown in Figure 1. In most cases there is good agreement between the four experts, but for Issues 7 (Collateral Damage) and 15 (Loss of Coastal Habitats) there is a significant outlier. It would be possible to canvass opinions amongst a greater range of aquaculture and marine biology experts to produce a mean score that more accurately reflects scientific opinion.

Mariculture may have some biodiversity impacts that are positive. In the spreadsheet positive impacts are Issue 21. One example of a potential positive impact is the removal of nutrients and phytoplankton by farmed bivalves. This may be beneficial in areas with artificially high nutrient inputs. Deciding whether an impact is positive or negative is not always easy and there is an element of subjectivity.

In the spreadsheet the positive impacts (Issue 21) are given a negative weighting (the mean of the four external experts' weightings for this issue). When all impacts are summed the positive impacts offset (to a minor extent) any negative impacts that have been identified.

3.2.5 Production of an Excel Spreadsheet

This item was relatively straightforward once the main principles had been defined.

During this exercise we realised that the overall weighted score could be expressed as a percentage of the theoretical maximum score (TMS). The TMS is simply the total score if 10 is assigned to each of the Issues 1-20 (Issue 21 is omitted in this calculation) and this is then multiplied by the weighting for each issue. The theoretical maximum score from each of the four experts was very similar, ranging from 1090 to 1160 (mean 1130).

Table 2 shows a hypothetical example of how the Excel spreadsheet calculates the overall weighted score. In this case the overall weighted score is 297.3, this can be expressed as a percentage of the TMS:

$$\frac{297.3 \times 100}{1130} = 26.3\%$$

3.2.6 Obtain Feedback from SARF

The SARF Secretariat, at the request of Aquatonics Ltd., circulated the spreadsheet and explanatory notes to members of the SARF board for comment. There were two responses. Most of the comments related to the methodology itself and no additional issues were suggested.

3.2.7 Amend Spreadsheet in the Light of Comments from SARF

No amendments to the spreadsheet were necessary, as no additional issues were suggested.

3.2.8 Produce guidance on the suggested scoring for each of the issues identified

For each Issue we developed Guidance Notes on the score to allocate. This scoring guidance we produced was generic, not specific to a species or location. We have decided to withdraw this scoring guidance in the final version of this report, as it was criticised by the reviewers of the draft report.

4. EXPLANATORY NOTES ON EACH ISSUE

1. Availability and sustainability of food

Internationally, 10 million tonnes of wild-caught fish are used to produce fish meal for the aquaculture industry and a further 22 million tonnes are used to make fish meal for chicken, pig and other animal feeds (Naylor et al, 2000). These figures compare with about 65 million tonnes of fish used for direct consumption by humans (Naylor et al, 2000).

The amount of damage caused by fishing to supply fish meal is strongly debated. A recent paper by Naylor et al (2000) raised significant concerns about current impacts and future trends, but there has also been a detailed rebuttal of many of these arguments (see Annex 4 of ICES WGEIM, 2002).

The biodiversity implications of providing fish meal for farmed carnivorous fish occur at sites that are usually distant from the aquaculture facility. However, for farmed bivalves the food supply is derived from local phytoplankton. The sustainability of food supplies for novel mariculture species will therefore depend to a large extent on the species farmed, and there will be many parallels with equivalent species that are already commercially farmed in Scotland.

For novel shellfish species the sustainability of food supplies is likely to be a minor issue, provided that the amount of local phytoplankton does not significantly decline due to the increased biomass of filter-feeding bivalves.

For those farmed finfish that require fish meal made from wild-caught fish the situation is more complex and will depend upon the wild species caught and whether their stocks are sustainable. Commercial fishing provide fish meal has been implicated as one of the causes of the decline in sandeel populations in the North Sea. In 2000 a ban on fishing sandeels in parts of the North Sea (north-east coast of Scotland to Northumberland and the Wee Bankie off the Firth of Forth) was announced by the European Union. The aim of this partial ban was to safeguard populations of puffins and kittiwakes.

The potential to diminish biodiversity due to the damage to the seabed caused by fishing and the bycatch from fishing to produce fish feed are also important issues.

2. Availability and sustainability of wild broodstock (eggs, larvae, juveniles or adults)

Definition of broodstock

"Specimen or species, either as eggs, juveniles, or adults, from which a first or subsequent generation may be produced in captivity, whether for growing as aquaculture or for release to the wild for stock enhancement" (Australian State of the Environment Committee, 2001).

Definition of free-ranging broodstock

"Aquatic animals of any species captured from the wild for the purpose of spawning" (US Fish and Wildlife Service, 2004).

The collection of wild specimens to produce broodstock can include all life stages, ie eggs, larvae, juveniles or adults (breeding or non-breeding). In some cases this will be an initial collection of adults to provide a broodstock in the aquaculture facility, but in other cases there will be a continuing demand for free-ranging broodstock, either at regular intervals or if there are losses of the farm's broodstock due to pollution, disease etc.

The availability of wild broodstock is likely to be an important issue for many novel mariculture species.

3. Introduction of genetically modified organisms (GMOs), either as target species or in food

At present GMOs are unlikely to be an issue for mariculture of novel species in Scotland, as the Strategic Framework for Scottish Aquaculture (Scottish Executive, 2003) makes clear in the extract below:

> "Genetically modified organisms (GMO)
>
> Although the principles of selective breeding are well established, there have been expressions of public concern about the use of genetically modified crops in the food chain and the appropriateness of their use in livestock production, in aquaculture as in agriculture. There are presently two main areas of potential application of GMO technologies in aquaculture.
>
> The first is the use of GMO vegetable products in fish feed, where their potential value lies in their contribution to the sustainability of feed ingredients as well as to more stable feed prices. However, so long as their use is linked with consumer concern, the industry in Scotland has declared that it will not use them.
>
> The second application is the use of GMO technologies (more specifically, transgenics) in breeding fish for commercial aquaculture use. This also plays no part in Scottish commercial aquaculture production. The industry considers, however, that, were the public perception of transgenics to change, it could not ignore the potential of the technologies. Any proposal to use transgenic fish would require the consent of the Scottish Ministers. If granted, approval would be based on the statutory advice of the Advisory Committee on Releases to the Environment and would also take into account advice from other relevant agencies

> such as the Food Standards Agency and Scottish Natural Heritage. Meanwhile, Scottish research institutions supporting the industry will continue to develop their knowledge as the application of genetic techniques may be expected to play some role in the future."

4. Genetic intergradation between wild stock and cultivated stock

In some cases the novel species will be one that naturally occurs locally and there will be a potential for the farmed species to breed with the wild stock. This may result in alteration of the gene pool and genetic weakening of the wild stock (Mork, 1991), especially if the escapes are large scale and frequent. These alterations are termed genetic intergradation (ICES WGEIM Report, 2005).

Escaped Atlantic salmon have been shown to have both indirect and direct genetic effects on wild populations (ICES WGAGFM Report, 2006). Indirect genetic effects occur due to behavioural, ecological, and disease interactions. These reduce the effective population size of the wild population and increase genetic drift. Competition with farm fish and hybrids, which are larger, can reduce wild smolt production. Direct genetic effects occur due to interbreeding with wild fish and backcrossing in subsequent generations.

A recent report by the ICES Working Group on the Environmental Interactions of Mariculture (ICES WGEIM Report, 2005) examined these genetic interactions in detail and came to the following conclusions:

> "No evidence has been found that commercially cultured aquatic organisms have novel alleles otherwise absent from feral populations of the same species. Differences in allelic frequencies have been noted. Interbreeding has been documented between escaped and feral Atlantic salmon. Interbreeding is more likely to occur in areas close to the location of the escape. The effect of intergradation is likely to be proportional to the relative number of wild and cultured organism interbreeding. Where only a few individuals are involved, the effects are likely to be less. Where relatively large scale genetic intergradation has occurred, there has been reduced fitness and survival of the feral population. Where studied, hybrids of single interbreeding events rapidly disappear from the feral population and the effect is likely to be reversible through natural selection over a period of a few years. Where large scale repeated escapes occur, the effects are likely to be larger and the consequences unpredictable. Metapopulation dynamics are likely to buffer the effects of occasional intergradation events, but not buffer effects from repeated large scale events."

Annex 4 of the ICES WGEIM Report (2005) is a preliminary assessment of the state of knowledge of the potential impacts of escaped turbot from aquaculture. Whilst this fish is not a novel species for aquaculture in Scotland, it is relatively new and the assessment is therefore useful when considering novel species. The following text extract shows some of the information that will be required when assessing genetic intergradation between a novel farmed fish and the wild population (references have been removed):

"Differences between the genome of wild and cultured turbot

In many turbot farms it is the practice to use wild-caught mature adults as broodstock. There is however evidence that more and more turbot farmers are selecting juveniles with high growth rates and less malpigmentation, in order to increase production outputs. Furthermore, several turbot farmers are obtaining fish from a select few hatcheries. For turbot, some evidence of lower allozyme heterozygosity and loss of genetic variability exists in farmed strains of turbot.

Conclusion: Genetic differences have been observed between wild and cultured turbot."

"Turbot escapees

Although turbot is mainly cultured in land based systems on recirculation, escapes are possible through outlets in flow through systems (when used) or by getting into dewatering channels by accident during sorting and handling of turbot and taken to the sea. Further impact on wild stocks could be expected through accidental release of fertilised eggs in the environment, since most incubation tanks are run in an open flow through system. The risk on escape will increase when culture systems are changed from on-land based systems to sea cage culture. In the latter, it is more likely that escapes could form a significant route for genetic interaction with the wild stock. Net cages can be damaged due to heavy weather conditions (storms), persistent predators such as seals that try to get at the fish, industrial accidents (human error or equipment malfunction), and even vandalism. So far, no information is available on the actual number of escaped fish from land based turbot farms, but the number is likely to be very small. However, with the use of sea cages for turbot, the risk on escapes could increase substantially, since accidents do happen. But it is predicted that the losses in net cage culture would be much lower than, for example the 20–25 incidents per year reported from 1998–2003 in salmon net pen aquaculture in Scotland.

Conclusion: escaped turbot from land based farms is likely, but in very small numbers, especially in land based flow through systems and during sorting and handling. The risk becomes much higher for net cage cultured turbot."

5. Escape of fertilised eggs, juveniles and adults

Escapes can occur for all types of farmed species (algae, invertebrates and fish) and are one of the main concerns regarding the impacts of the aquaculture industry worldwide, especially if the species is non-native (for example Atlantic salmon on the Pacific coast of North America). In general, the ecological outcomes of species transfers are highly unpredictable, and when effects are observed they are usually negative for the native populations, species and ecosystems (ICES WGAGFM, 2006).

It seems unlikely under the present regulatory framework in Scotland that any non-native species will be used in mariculture. Issue 5 will therefore primarily be used to consider impacts of novel species that are native to Scotland.

The escape of native species can cause problems, as shown by the escape of farmed Atlantic salmon in Scotland and Norway (see Issue 4). In the context of this scoring system for novel species some of the impacts of escaped eggs, juveniles and adults are considered in Section 4 (Genetic intergradation) and Issue 13 (Transfer of diseases or parasites). Issue 5 addresses other aspects, such as competition for space, food and mates. This competition is both intra-specific (with the same species found locally) and inter-specific (with other species found locally).

To make an adequate assessment for Issue 5 it will be necessary to obtain detailed information on the ecology and physiology of the novel species. Important factors will include:

- their reproductive method;
- survival of released gametes, fertilised eggs and juveniles in the conditions expected at the proposed development site;
- time spent in the water column and likely transport by currents;
- food preferences of juveniles and adults; and
- an analysis of the locally found species they will compete with for food and space.

A site-specific assessment will be needed, as well as an assessment of each novel species. The cost of this assessment may be relatively high.

6. Competition between escaped non-native species and native species

This issue is only relevant where the farmed species is not native to Scotland. It can be ignored (given a score of zero) for all proposals that involve native Scottish species.

We define non-native in the context of this report as those species that do not naturally occur in Scotland. This definition is not precise, as global warming or other factors causing a migration of marine species into Scottish waters are likely to increase the number of marine species found "naturally" in Scotland.

Non-native species can sometimes thrive in new environments, either as an initial population explosion that dies away, or as a longer-term component of the local flora and fauna. They can have severe adverse impacts on the local biota, by competing for space (eg the seaweed *Sargassum muticum*, recently found on the west coast of Scotland) and food. Carnivorous species may become important predators.

The main legislative acts controlling the release of non-native flora and fauna in the UK are the Wildlife and Countryside Act 1981 and The Fish Health Regulations 1997 (SI 1997 No 1881).

Section 14 of the Wildlife and Countryside Act makes it an offence to release or allow to escape into the wild any animal which is not ordinarily resident in or a regular visitor to the UK, or which is established in the wild and listed in Schedule 9 of the Act, without a license.

The Fish Health Regulations 1997 implement Council Directive 91/67/EEC Concerning the Animal Health Conditions Governing the Placing on the Market of Aquaculture

Animals and Products) and Decisions made under it. The Regulations control the movement into Great Britain from elsewhere in the EU of:

- All live molluscan shellfish, their eggs and gametes;
- All live fish their eggs and gametes; and
- Certain dead fish.

With respect to the cultivation of a new species, the relevant authority should follow the procedures laid down in the ICES Code of Practice on the Introductions and Transfers of Marine Organisms (2005).

It would appear that it is not illegal to farm non-native species in Scottish waters, but the necessary licences and permits would be difficult to obtain. Detailed consideration would have to be given to the possibility of escape of the non-native species and it seems unlikely that open-water mariculture would be approved.

7. 'Collateral damage' - escapees sought as food by humans, leading to habitat disturbance

This term covers escapees from a mariculture facility which are sought as food by humans, leading to habitat disturbance or destruction. As an example, harvesting the non-native American hardshell clam (*Mercenaria mercenaria*) in Southampton Water and the Solent resulted in damage to eelgrass (*Zostera*) beds (Cox, 1991).

For novel species this issue is most likely to occur for bivalves that are in high demand in the UK.

8. Introduction of veterinary medicines

Historically, a wide range of veterinary medicines (eg antibiotics and pesticides) have been used in mariculture, mainly for finfish and shrimps. Many had never been specifically evaluated from the perspective of their effects on the aquatic environment (Food and Agriculture Organization, 1997). In Scotland and many other European countries the use of veterinary medicines is declining. This is partly due to the strong regulatory framework for their use.

There is now a tripartite agreement between the European Union, Japan and the USA regarding research development, approval and quality control procedures for testing of veterinary medicinal products. This process is managed by the Veterinary International Conference on Harmonisation (VICH) (Alvarez & Fortsch, 2005).

Use of veterinary medicines in the UK is regulated by the Veterinary Medicines Directorate.

Concentrations of veterinary medicines in food intended for human consumption is regulated by The Animals and Animal Products (Examination for Residues and Maximum Residue Limits) Regulations 1997.

A recent report by the Scottish Association for Marine Sciences examined the impact of veterinary medicines used to control sea lice on the ecology of Scottish sea lochs (SAMS, 2005). The report examined impacts outside the immediate mixing zone and found that the veterinary medicines were not having any impacts that could be distinguished from the natural variability of the ecosystem.

The Code of Good Practice for Scottish Finfish Aquaculture (Scottish Salmon Producers' Organisation et al, 2006) contains the following text on the use of veterinary medicines:

> **"Use of Licensed and Approved Treatments**
>
> The use of authorised veterinary medicines and other treatments to protect fish welfare is a legitimate aspect of fish husbandry. Only those substances that are permitted under European and UK legislation must be used in fish destined for human consumption.
>
> Veterinary medicines should be used prudently and in accordance with the conditions set out in the data sheet. Prescription only medicines (POMS) must only be used under the instruction of a veterinary surgeon.
>
> Details of all treatments used should be covered in written Control Procedures. Each Written Control Procedure should describe:
>
> 1 the involvement of the nominated veterinary surgeon;
> 2 the justification for the use of the treatment;
> 3 the nature of treatment used;
> 4 the circumstances under which fish are treated;
> 5 official controls on the use of the treatment including, as appropriate, any discharge into the environment, which must be covered within the Discharge Consent; and
> 6 measures in place to prevent unacceptable residues of the treatment substance remaining when the fish are harvested.
>
> Full records of the use of licensed and approved treatments must be maintained for a period of 3 years, for POMS the period is 5 years.
>
> **Freedom from Unacceptable Residues of Veterinary Medicines and Treatments**
>
> All farms producing salmonids for the table are currently tested for residues of veterinary medicines under the terms of The Animals and Animal Products (Examinations for Residues and Maximum Residue Limits) Regulations 1997. As the production of other species increases, these will also be included in the sampling programme.
>
> Farmers should be able to demonstrate that fish harvested for human consumption are free of unacceptable residues of all of the veterinary medicines and treatments used in their production:
>
> 1 They must maintain records of the use of all medicines and treatments.
> 2 They must maintain records which demonstrate that the minimum withdrawal period for each medicine or treatment used has been observed.

Novel mariculture species will be host to some parasites not found in species that are currently farmed. They are also likely to have diseases that are new to the Scottish aquaculture industry. It seems unlikely that new veterinary medicines will be required to specifically deal with parasites and diseases of novel species.

9. Reduced water quality due to excretion and respiration

The water quality in the immediate vicinity of finfish mariculture can be adversely affected by excretion and respiration. Examples are lower concentrations of dissolved oxygen and higher concentrations of nitrogenous chemicals such as ammonia. Oxygen depletion is a very localised impact that usually occurs only in the immediate vicinity of a fish farm at slack tide when the current speeds fall close to zero (Silvert, 2005).

Novel finfish and shellfish mariculture species are unlikely to pose any particular problems relating to water quality. Information on similar species currently being farmed in Scotland will probably be sufficient to assess potential impacts of novel species on water quality. However, it is possible that seaweeds may pose new problems, especially if they may die and decompose during adverse conditions.

10. Reduced water quality due to nutrients released and the BOD and COD of the food, faeces and pseudo-faeces whilst in the water column

Monitoring nutrient release from fish farms is usually by chemical analysis methods but macroalgal and phytoplankton growth can also be used (Dalsgaard and Krause-Jensen, 2006). In many cases the elevated concentrations only affect relatively small areas around the fish farm. In a study of four Mediterranean fish farms producing sea bream and sea bass significant increases in growth of the alga *Ulva* sp. and phytoplankton were within 150m downstream of the fish cages, in the dominant current direction (Dalsgaard and Krause-Jensen, 2006). However, at a farm in Cyprus the phytoplankton bioassay showed increased growth at up to 920m from the fish cages.

A review of the data on Harmful Algal Blooms (HABs) in Scottish coastal waters examined the issue of whether fish farming was responsible for recent increases in HABs (Tett and Edwards, 2002). The authors wrote:

> "Concerning the allegation that increases in marine salmonid farming have been responsible for apparent increases in HABs in Scottish waters, we conclude that neither the increase in HABs nor the link to fishfarming is supported by the available direct evidence - which is, however, incomplete. There seems little doubt that human influenced nutrient enrichment is having some effect on some Scottish waters, but the mathematical logic involved in the calculation of equilibrium concentration enhancements suggests that fish farms are likely to have a detectable effect only in enclosed basins in which water exchange is slow in relation to nutrient loading. More research is needed."

Uneaten food is a significant source of oxygen demand in some fish farms, but in many cases the food will fall to the seabed quickly and most deleterious effects will occur there. If the food is broken into small fragments or is close to neutral buoyancy some of the biochemical oxygen demand (BOD) and chemical oxygen demand (COD) will occur in the water column. Faeces and pseudo-faeces also have the potential to remove oxygen due to their BOD and COD. The extent of this effect will be determined by factors such as their buoyancy and local current speeds throughout a tidal cycle.

11. Reduced sediment quality due to food, faeces and pseudo-faeces falling to seabed

In the early years of caged rainbow trout farming in freshwater up to 30% of the food passed through the cages uneaten (Carss, 1990). Food wastage in modern mariculture systems is approximately 2% for extruded food and 9% for pelleted food (Dosdat, 2001). Overall, food wastage rates on modern finfish farms are 5% or less (Brooks and Mahnken, 2003).

Faeces (and in the case of bivalves pseudo-faeces) also fall to the seabed. Overall it has been estimated that 300 - 1000 kg of solids (food and faeces) are produced per tonne of finfish production (Beveridge et al, 1994).

Considerable improvements have occurred in food conversion ratios (FCRs) in the salmon industry in recent years (ICES WGEIM, 2002). These improvements are due to a range of factors, including:

- a better understanding of the metabolic requirements of fish;
- an understanding of the cyclical nature of fish appetites;
- modification of food requirements with fish age;
- improving food distribution devices; and
- improvement of rearing conditions to improve FCRs (e.g. FCRs in the Norwegian salmon industry have decreased from 1.5 to 1.1 in the last ten years) (ICES WGEIM, 2002).

These improvements will need to be adapted to emerging and new species. FCRs are still very high in sea bass farming in Greece, normally 2.0 on average, even though values of 1.2 have been observed at experimental scale (ICES WGEIM, 2002).

The impact of faeces and pseudo-faeces from mussels (*Mytilus edulis*) on the surrounding sediments have been assessed at two suspended culture farms in south west Ireland (Chamberlain et al, 2001). Both sites had been in operation for over 8 years, produced over 100 MT of mussels per annum and were in low energy environments. Settling velocities were quite low, <0.5 cm/s for faeces and <0.8 cm/s for pseudofaeces. There was a marked difference between the two mussel farms, with no observed effects of mussel biodeposits at one site, but effects up to about a radius of 40m from the other (Chamberlain et al, 2001). The unaffected site had slightly higher average current velocities, and this may be the main reason for the difference in impacts. Other studies of mussel farming also show considerable differences in impacts (various studies cited by Chamberlain et al, 2001).

These various waste products from fish and shellfish farming may affect a wide range of chemical parameters in the sediments. A recent study of the impacts of mussel rafts on sediments showed that the biodeposits had significantly higher silt and clay content, total organic carbon, total inorganic carbon and total nitrogen, but no significant differences in pH or redox potential (Otero et al, 2006).

SEPA have a policy of allowing an allowable zone of effects (AZE) around fish farms. This is described in more detail below.

Allowable Zone of Effect (AZE)

The following text is from SEPA (2004a):

> In common with the approach the agency applies to other types of effluent discharges, SEPA acknowledges the need for a mixing zone around cage fish farms where pollutants are at first diluted. SEPA accepts that the water and seabed are changed from their normal state within this area, known as an allowable zone of effects (AZE). It is defined as:
>
> "The area (or volume) of seabed or receiving water body in which SEPA will allow some exceedance of the relevant environmental quality standard or some damage to the environment".
>
> The concept is fundamental to the Scottish system of environmental management. It follows that any modelling approach used in regulating effluent discharges must allow appropriate boundaries to be set, defining the extent of the AZE and therefore where SEPA expects the EQS to be achieved, taking account of natural processes of dispersion and degradation of the various types of wastes.

Modelling carbon fluxes to the seabed is an important component of SEPA's regulatory regime for fish farms. Modelling is carried out using DEPOMOD, a collection of sub-models which have undergone various improvements and refinements over the years. Data requirements for DEPOMOD include the food quantities, percentage of food that is uneaten, the carbon content of the food, current velocities, current directions, water depth and settling rates of food and faeces.

In a Canadian study using the DEPOMOD model to predict carbon flux to the seabed it was found that a rapid decline in Infaunal Trophic Index (a measure of organic enrichment and disturbance to benthic communities) was observed in most samples where predicted carbon flux was >1 g C m^{-2} d^{-1} (Chamberlain et al, 2005). This is equivalent to >0.365 kg C m^{-2} y^{-1}. In Scotland it has been found that, as a rule of thumb, degraded benthic conditions occur where carbon deposition rates exceeds 0.70 kg C m^{-2} y^{-1} (Gillibrand et al, 2002). In areas where deposition rates exceed this value, the diversity of benthic fauna is significantly reduced.

Where there is more than one fish farm in a Scottish loch there is a need to examine the cumulative carbon loading. For each farm in the loch, the cumulative carbon loading values for each calculated area are summed, until the value exceeds the critical value of 0.70 kg C m^{-2} y^{-1}. The area corresponding to that loading is then recorded as the "degraded" seabed area for that farm. This is repeated for each farm in the loch, and the "degraded" areas are then summed to give the total "degraded" seabed area (Gillibrand et al, 2002).

Settlement rates of faecal pellets collected below commercial cages for sea bream and sea bass have been assessed and the results used in a sensitivity analysis of the particle tracking model DEPOMOD (Magill et al, 2006). The results showed considerable variations between different model runs using mean settling rates and distributional data. Distributional data for sea bass produced fluxes three times higher at 0 m but five times less at 50 m. For gilthead sea bream the model using distributional data produced fluxes over twice as high at 0 m but fluxes at 50 m were only 50% of those predicted using the mean settling rates (Magill et al, 2006). A Canadian study also showed that predictions of benthic carbon flux varied greatly depending upon the sinking rates used for the food and the faeces (Chamberlain et al, 2005). These results emphasise the importance of obtaining data for each novel species and testing settlement models with various versions of the data set.

Any proposed novel mariculture species in Scotland will need to be carefully assessed for the impact of its faeces (and pseudo-faeces for bivalves) and waste food on nearby sediments. Information will be required on likely FCRs in the production unit, amount of uneaten food, and settlement rates of uneaten food, faeces and pseudofaeces.

SEPA now favour highly dispersive sites and new sites are less likely to be in areas where localised organic enrichment is a danger (Scottish Executive, 2006). Whilst the scientific basis for this approach is understandable, it does mean that the local flora and fauna are less likely to be adapted to high sediment loads. In our opinion future mathematical modelling of sediments may need to include the movement of sediment on the sea bed, as this could be a critical factor for many species in highly dispersive areas.

12. Accidental importation of other species with the target species

This issue includes all accidental imports of species accompanying the target species. The accidentally introduced species could themselves be native or non-native and could include organisms such as viruses, plants and vertebrates. Consignments of fish, invertebrates or algae may contain a variety of non-target species. These can either be large but difficult to distinguish from the target species, or be too small to be seen without a microscopic inspection of the entire consignment. In many cases these non-target species will have no detrimental effects, others may be native and carry diseases and some may be non-native and invasive.

Historically, many non-native marine species have been spread by aquaculture. It has been estimated that 31% of all UK non-native marine species were unintentional introductions due to mariculture and a further 8% were deliberate commercial introductions (Eno et al, 1997). Examples of unintentional introductions in the UK include several species of seaweed introduced with oyster spat (Eno et al, 1997). One invasive species that is well-documented is *Sargassum muticum*, which entered northern France via this route and probably reached the UK by "rafting" (Eno et al, 1997). *Sargassum muticum* has recently been recorded on the west coast of Scotland (Scottish Natural Heritage, 2004).

It appears that bivalves may be a particular problem, probably because a wide variety of seaweeds and other fouling organisms attach themselves to the valves and cannot always be completely removed. Commercially farmed seaweeds may also be a source of non-target species, as most seaweeds harbour a diverse invertebrate fauna which can be difficult to separate completely, even by repeated washing. Some seaweeds have other epiphytic seaweeds on them and these can be difficult for the non-specialist to see and remove.

Of the twenty-four non-native marine species found in Scottish waters ten have potentially harmful effects on the environment and/or on commercial interests (Scottish Natural Heritage, 2004). They are the algae *Polysiphonia harveyi, Colpomenia peregrina, Sargassum muticum, Codium fragile* subsp. *tomentosoides* and subsp *atlanticum*, and the invertebrates *Marenzelleria viridis, Balanus amphitrite, Elminius modestus, Crassostrea gigas* and *Styela clava*. Their effects include the displacement of native species, competition with native species for food and space, disruption of commercial oyster beds and the fouling of ships, buoys and harbour structures.

Many non-native species fail to become established and die out naturally.

Regulation of the import of non-target species has been significantly improved in recent years. The Code of Good Practice for Scottish Finfish Aquaculture (Scottish Salmon Producers' Organisation et al, 2006) provides a range of useful advice on this issue.

13. Transfer of diseases or parasites from the novel species to local wild or farmed species

The spread of diseases and parasitic organisms between farms and to wild populations is one of the most serious environmental impacts of aquaculture (Silvert, 2005). This issue has been at the heart of the debate about the impacts of Atlantic salmon farming on wild salmon stocks.

Pathogens and other parasites could either be imported with the target species (see Issue 12) or they could occur naturally around the mariculture facility but reach high infection rates in the farmed species due to stocking densities and water quality. The pathogens or other parasites could be transmitted to wild species or to nearby farmed species.

Unfortunately it is very difficult to mathematically model the spread of diseases and parasites. Calculation of the probability of transmission depends on many factors, for example intensity of infection, persistence of disease organisms in the water column and virulence, so that theoretical calculations are almost impossible to make with any degree of reliability (Silvert, 2005).

A study by Carss (1990) showed high densities of native marine fish, particularly saithe (*Pollachius virens*) around marine cages holding Atlantic salmon. This close proximity of caged and wild fish may increase the possibility of transfer of pathogens (Carss, 1990).

A recent report by the Fisheries Research Services (FRS) examined the disease risks and interactions between farmed salmonids and novel mariculture species (Anon, 2005). The report made thirty-one recommendations on how to reduce the possibility of disease transfer between farmed salmonids and novel mariculture species.

14. Use of antifoulants and other biocides on cages and other structures

Biocides are mainly used to keep structures free of fouling organisms. Fouling organisms are a significant economic issue for mariculture. A recent EU funded project (CRAB -

Collective Research on Aquaculture Biofouling) is intended to provide low cost solutions to biofouling (www.crabproject.com). It has been estimated (Willemsen, 2005) that the cost of changing nets on medium sized salmon farmers is €60000 per year and biofouling on fish cages and shellfish costs the European industry 5 - 10% of the industry value (up to €260 million/year). In some sectors the costs of manual cleaning of biofouled shellfish amounts to 20% of the product market value.

Novel mariculture species are unlikely to pose any new problems in this area.

15. Loss of coastal habitats such as wetlands due to production and ancillary facilities

SEPA and SNH both have important roles in protecting coastal habitats, especially those that have been designated for their nature conservation interest.

The Habitats Directive (92/43/EEC) and the Wild Birds Directive (79/409/EEC) concern the protection and conservation of natural habitats. SEPA is a "competent authority" with regard to all areas designated in Scotland under these directives, that is Special Areas of Conservation (SACs) and Special Protection Areas (SPAs), collectively known as European sites (SEPA, 2005).

For Sites of Special Scientific Interest SEPA must consult with SNH over any activities for which SEPA has responsibility, if those activities are likely to damage or destroy the features for which any Site of Special Scientific Interest (SSSI) has been notified. Since the SSSI designation is confined to the area above Mean Low Water Mark of Spring Tides, the assessment of most consent applications are unlikely to be affected. Discharges from sites located close to shore could, however, lead to impacts on intertidal SSSIs under the appropriate hydrographic conditions (SEPA, 2005).

Marine Consultation Areas (MCAs) are the principal non-statutory designation produced for marine areas in Scotland. They were identified by the former Nature Conservancy Council (now Scottish Natural Heritage) as:

> "A list of marine coastal areas….. identified as deserving particular distinction in respect of the quality and sensitivity of their marine environment and where the scientific information available fully substantiated their nature conservation importance".

There are 29 MCAs in Scotland, mostly in Western and Northern Scotland, and in the Western and Northern Isles. Although the MCA is not a statutory designation, SEPA's statutory guidance on sustainable development indicates that protecting the natural heritage interests of non-statutory designated areas is a contribution that SEPA should make to achieve sustainable development. In addition, SEPA has a duty in the exercise of any of its functions, to have regard to the conservation and enhancement of the natural heritage of Scotland. Clearly identified natural heritage interests such as those of MCAs are not dismissed without consideration when dealing with consent applications.

The farming of novel species is unlikely to raise any new issues relating to the loss of coastal habitats. The existing regulatory framework should prevent large-scale losses of important wetland and other coastal habitats.

16. Physical changes to habitat due to aquaculture facilities

Habitats may be altered by the introduction of aquaculture facilities such as nets, ropes and cages. These will be colonised by a variety of species that occur in the locality but may be unusual at that particular location. In some cases these structures will increase local biodiversity but reduce the naturalness of the site.

Novel species are unlikely to pose any new problems regarding physical changes to habitats.

17. Physical smothering of important habitats from fish and shellfish farms

In addition to possible impacts due to reduced sediment quality, the physical smothering of habitats by food, faeces and pseudo-faeces falling to the seabed can have adverse effects. This is likely to be particularly important where there are low current speeds and habitats such as seagrass beds that are susceptible to smothering.

The existing SEPA regulations regarding modelling of sedimentation rates is likely to provide adequate protection from physical smothering, except in the immediate vicinity of the mariculture operation. Any localised impacts could be mitigated by re-siting away from particularly sensitive habitats.

18. Disturbance due to aquaculture operations including harvesting

Aquaculture operations such as movements of facilities and harvesting can disturb the sediment and some operations may be noisy and disturb fish, birds and cetaceans.

The impacts of harvesting of shellfish are dependent upon the method of harvesting. Towed dredges or suction pumps for subtidal bivalves have localised impacts on the benthic infauna and epifauna. The severity of the impact of dredging depends upon the weight of the dredging gear used, frequency of dredging and whether there are long-lived and fragile wild species in the area (eg sea fans) that will be damaged. Recovery times for dredging in the worse cases may be many years (Kaiser, 2001). Harvesting of trestle grown and suspended bivalves has little effect on the environment except possible disturbance to feeding birds (Kaiser, 2001). Mechanical harvesting of intertidally grown bivalves is potentially damaging to the benthic habitat and may disturb birds such as over-wintering waders.

Novel aquaculture species are unlikely to present any new challenges in this area.

19. Attraction of predators to the fish/shellfish farm and control measures such as scaring or culling.

A wide variety of predators are attracted to fish and shellfish farms. They include seals, cormorants, shags, herons and eider ducks. Although a variety of control measures can be used, some of these (eg loud sounds) may also impact on wildlife. Some of the predators may become trapped or entangled by nets and may be injured or die. Others may be shot, either legally or illegally.

The interactions between aquaculture and seals have recently been examined in a report by the Scottish Executive (2006). It stated that "it is in the companies' interest to locate away from seal haul out areas. Where predation by seals is a problem acoustic deterrent devices (ADDs) are used. The high frequency sounds which are emitted by ADDs are designed to exclude seals from the immediate area. Their use, and occasional permitted shooting of seals, is likely to come under scrutiny in areas (or close to such areas) proposed for SAC status for seals or in areas where cetaceans occur due to their increased sensitivity to high pitched acoustic noise."

The use of acoustic deterrents has been questioned because of the potential problems caused for cetaceans (Scottish Office, 2002). Cetaceans (dolphins, porpoises and whales) are much more sensitive to noise and a high pitched sound that might inconvenience a seal might cause pain to a cetacean. It is likely that powerful acoustic deterrents exclude cetaceans from a large area. A Canadian study indicated that killer whales were excluded from a 10 km radius of such a device (Scottish Office 2002). This finding is particularly important for exposed sites, where sound transmission distances might be considerably greater than in enclosed sea lochs. Seal management is crucial in maintaining the containment integrity of fish cages, acoustic deterrents have other environmental impacts diminishing their usefulness. There is insufficient information on coastal marine noise from other sources to easily quantify the degree of extra hazard to cetaceans (Scottish Office, 2002).

20. Litter and debris from farms e.g. plastic bags and wrapping

Litter, especially items that can be mistaken for prey, cause mortalities in a wide range of marine species, including fish, cetaceans and turtles. Fish farms are only one of the many potential sources of litter in the marine environment, but where they operate in remote areas they have the potential to be a significant source. We are not aware of any study that examines the relative contribution of aquaculture to the problem of marine litter.

Photographs taken by SeaLife Surveys and the Hebridean Whale and Dolphin Trust have shown that a number of minke whales have been found to have creel lines and plastic straps wrapped around their rostrums (Gill et al, 2000). Between 1992 and 2000, 15 out of the 70 minke whales stranded in Scotland died due to entanglement. Entanglement may also cause injury and wounds as the animal tries to disentangle itself from netting or ropes, which can also subsequently lead to infections.

Novel mariculture species are unlikely to pose any new problems in this area.

21. Positive effects such as plankton & nutrient removal by shellfish farms or nutrient removal by seaweeds

Mariculture can have some impacts that are positive. Probably the best example is the use of bivalves to remove plankton and nutrients from coastal waters that receive nutrient discharges from sewage works and agricultural discharges.

Deciding whether an impact is positive or negative is not always easy and there is an element of subjectivity. For example, if bivalves are raised near to finfish cages it is possible that the bivalves will bioaccumulate anti-foulants and medicines. The bivalves could also perhaps bioaccumulate and replicate finfish pathogens (Anon, 2005). More research is needed into these questions before we can be sure that shellfish farming is always a good method of reducing nutrient concentrations.

Seaweeds can be used in polyculture with farmed finfish to remove some of the excess nutrients. If seaweed culture is proposed as an additional enterprise close to an existing finfish farm then it would score well on Issue 21 (positive impacts).

In the spreadsheet the positive impacts are given a negative weighting; when all impacts are added the positive impacts offset (to a minor extent) any negative impacts.

5. DISCUSSION

5.1 Application of the Technique

This technique may have some value for mariculturalists who are considering novel species. Considerable information will be required by the mariculturalist and their consultants in order to provide sensible scores for each issue. The scoring system may help elucidate the likely differences in biodiversity impacts between alternative sites or alternative species being considered.

All the individual weighted scores are added together by the spreadsheet to produce an overall score that can be used to screen applications into the following categories:

Low risk
Medium risk
High risk
Very high risk

The spreadsheet calculates the percentage of the total possible score. Proposed developments involving novel species can be assigned to one of the above risk categories using this percentage figure. The bands have not been agreed with regulatory bodies such as SEPA and SNH, but the following are suggested:

Low risk to biodiversity	0-25%
Medium risk to biodiversity	25-40%
High risk to biodiversity	40-60%
Very high risk to biodiversity	>60%

5.2 Mitigation

The effect of mitigation on the scores can easily be calculated using the spreadsheet.

Total weighted scores can be calculated for the development as proposed and for the development with mitigation of the most important issues. This will allow the developer to focus attention on the most important issues relating to biodiversity. If a developer is considering more than one species the spreadsheet could be used to determine which would be more acceptable.

The total weighted score can also be reduced by obtaining a higher score on Positive Impacts (Issue 21). For example, it would be possible to have management procedures that ensured not only the removal of litter created by the farm, but also removal by staff of any other litter they encounter. This could be used by the developer to obtain a higher score for Issue 21, which, as it has a negative weighting, results in a lower total weighted score.

Mitigation measures for the main issues relating to marine finfish aquaculture have been summarised by Hargrave et al (2005). Table 1 from their publication is shown in an adapted form in Table 3. These mitigation measures are equally relevant for those species already commercially farmed in Scotland and for novel species.

TABLE 3. MITIGATION MEASURES AND RISK MANAGEMENT (adapted from Hargrave et al, 2005)

Issues	Risk management approaches (mitigation)
Local (cage scale), acute, short to medium term temporal, predictable effects (managed on a site-by-site basis)	
Dissolved oxygen depletion	Reduce fish density
Sediment organic enrichment	Move cages within or from site (fallowing)
Release of toxic chemicals	Minimise use, controlled applications
Inlet-scale, intermittent to chronic spatial and temporal effects, difficult to predict (modified by cumulative effects of all anthropogenic activities in a specified area)	
Nutrient enrichment	Siting to maximise dispersion
Antibiotic resistance	Increased use of vaccines, disease control to minimise antibiotic use
Harmful algal blooms	Phytoplankton monitoring
Mortality (temperature etc)	Monitoring, care in site selection
Mortality (disease)	Implement improved husbandry and disease control plans at all farm sites
Cumulative effects of all anthropogenic inputs	Develop and implement integrated management plans
Regional, broad-scale, long-term, unpredictable	
Escapement (genetic interactions)	Improved containment infrastructure
Feed manufacturing	Assessment of impacts of harvesting on wild stocks for feed production

6. WORKED EXAMPLE (HYPOTHETICAL)

Table 2 shows how the spreadsheet is used to calculate the overall risk to biodiversity of a novel aquaculture species. This is a hypothetical example, of a native bivalve (not currently farmed in Scotland) that requires no veterinary medicines, but large areas for cultivation. The hypothetical site is in Scotland, at a location with good water exchange. The weightings in Column B are the mean weightings from the 4 external experts. These apply to any proposed aquaculture development and are not specific to this hypothetical example. All the scores in Column C were produced by Aquatonics Ltd, not the 4 external experts.

The total weighted score in this hypothetical example is 297.3, which is 26.3% of the maximum possible score of 1130. This would put the biodiversity risk just into the medium band. If necessary it would be possible to get into the low biodiversity risk band by examining possible mitigation measures for high scoring issues such as 5 (escape of fertilised eggs, juveniles and adults) and 13 (transfer of pathogens and other parasites).

7. FUTURE WORK

The spreadsheet approach is highly flexible, eg new issues can be added, weightings can be revised, and divisions between levels of biodiversity impact can be amended.

To develop this idea further would require inputs from a larger number of experts. They could provide additional advice on the weightings for each issue. They could also give guidance on the allocation of scores for each issue.

Mariculturalists may find this spreadsheet based approach useful in their initial planning for the farming of novel species. It may assist in making choices between two or more potential marine species that could be farmed.

8. CHALLENGES POSED BY NOVEL SPECIES

Assuming that the novel species is one that is native to Scotland, the main challenges relate to knowing enough about its ecology and physiology to understand how it will perform in aquaculture, and how it will impact on biodiversity if it escapes into the wild. Some of the issues considered in this report are general to a range of mariculture species and are unlikely to require new data for a novel species. For example:

Issue 1. Novel species are unlikely to have new impacts on biodiversity issues relating to supply of food. The only exceptions would be if their food requirements were unusual and required exploitation of new stocks or threatened stocks.

Issue 3. Due to the current regulatory view on GMOs in Scottish aquaculture novel species are unlikely to raise any new questions relating to GMOs.

Issue 6. Not relevant if the novel species is native to Scotland.

Issue 8. It is unlikely that a novel species will require veterinary medicines that are not currently used in Scottish mariculture.

Issue 9. Novel species are unlikely to raise any new questions relating to impacts on water quality due to excretion and respiration.

Issue 14. Novel species are unlikely to raise any new questions regarding the use of antifoulants and other biocides.

Issue 16 -21 are unlikely to raise any new questions for novel species.

Other Issues will require provision of data relevant to that species. The data will probably by acquired by a combination of thorough literature reviews of the ecology of that species and targeted scientific studies. These Issues are:

Issue 2. Novel species may raise new questions relating to availability and sustainability of wild broodstock.

Issue 4. Novel species are likely to raise new questions regarding genetic intergradation with wild stocks.

Issue 5. Novel species will raise new questions relating to their escape and survival in the wild.

Issue 7. The possibility of escaped species being harvested will be determined by their ease of harvest and market value. It is likely that novel shellfish species will require the most careful consideration in this respect.

Issues 10 and 11. New data are likely to be required for shellfish and finfish, for example food amounts, food wastage, settling rates of food and faeces (and pseudo-faeces for shellfish).

Issue 12. The accidental importation of non-target species may require considerable monitoring to determine which other species may be accidentally imported or transported between different water bodies.

Issue 13. Transfer of diseases or parasites from the novel species to local wild or farmed species) is likely to require a detailed assessment by experienced scientists. Additional analysis of the diseases and parasites carried by the novel species may be required.

Issue 15. Loss of coastal habitats may be an issue for some novel species, especially if they require an unusually high area of land-based facilities. This could be, for example, because they are high value products that can be raised in intensive land-based culture systems rather than in open water.

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Figure 1. Weightings Provided by Four External Experts

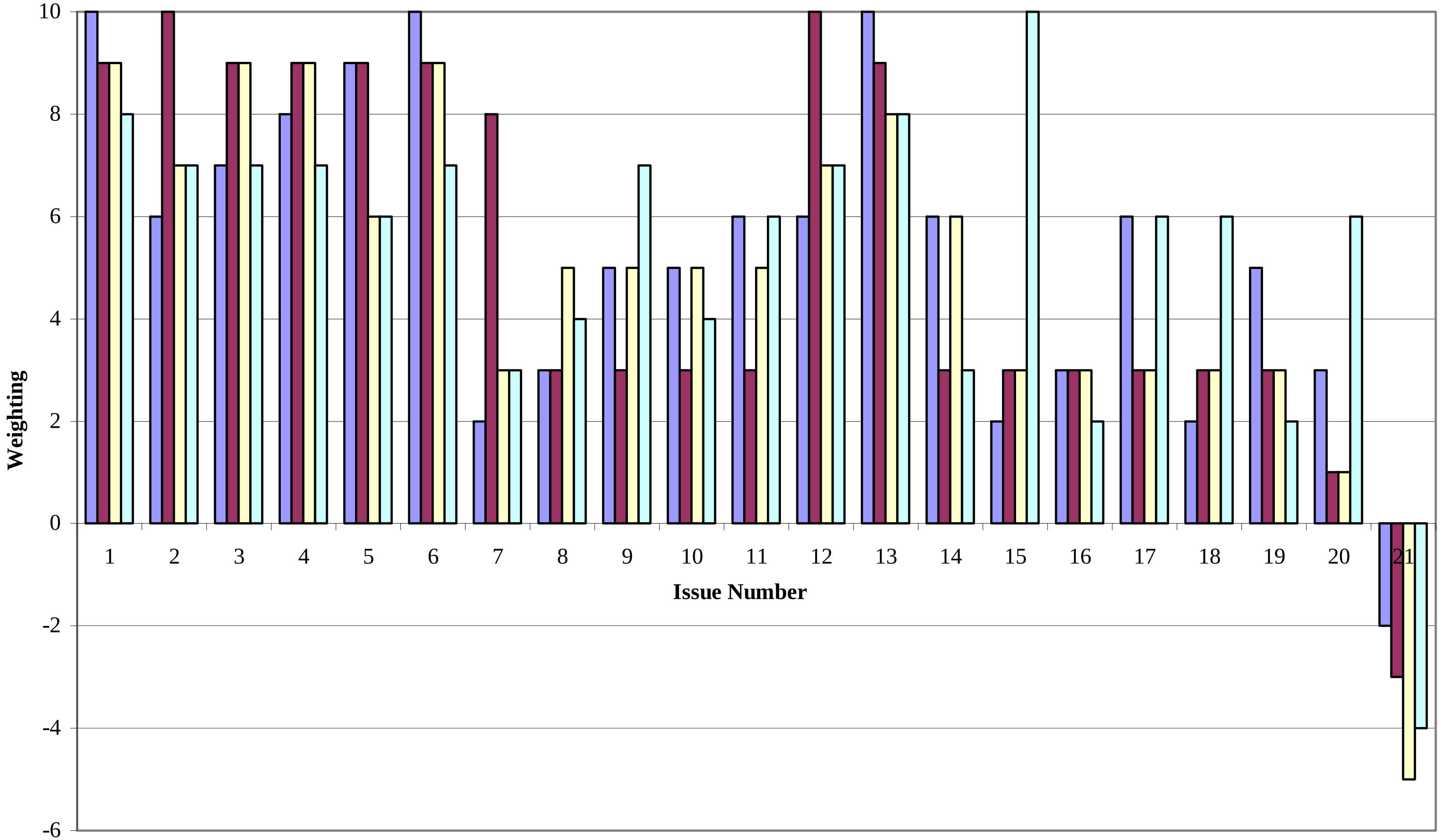

TABLE 1. SCALE OF IMPACTS FOR EACH BIODIVERSITY ISSUE	LOCAL	REGIONAL	NATIONAL	INTERNATIONAL
1. Availability and sustainability of food	Possible	Possible	Likely	Likely
2. Availability and sustainability of wild broodstock (eggs, larvae, juveniles or adults)	Likely	Likely	Likely	Likely
3. Introduction of genetically modified organisms, either as target species or in food	Possible	Likely	Likely	Possible
4. Genetic intergradation between wild stock and cultivated stock	Likely	Likely		
5. Escape of fertilised eggs, juveniles and adults	Likely	Likely	Likely	Possible
6. Competition between escaped non-native species and native species	Likely	Likely	Possible	Possible
7. 'Collateral damage' - escapees sought as food by humans, leading to habitat disturbance	Likely	Possible		
8. Introduction of veterinary medicines	Likely			
9. Reduced water quality due to excretion and respiration	Likely			
10. Reduced water quality due to nutrients released and the BOD & COD of food, faeces & pseudo-faeces whilst in the water column	Likely			
11. Reduced sediment quality due to food, faeces and pseudo-faeces	Likely			
12. Accidental importation of other species with the target species.	Likely	Likely	Possible	Possible
13. Transfer of diseases or parasites from the novel species to local wild or farmed species	Likely	Likely	Possible	Possible
14. Use of antifoulants and other biocides on cages and other structures	Likely			
15. Loss of coastal habitats such as wetlands due to production and ancillary facilities	Likely			
16. Physical changes to habitat due to aquaculture facilities	Likely			
17. Physical smothering of important habitats	Likely			
18. Disturbance due to aquaculture operations including harvesting	Likely			
19. Attraction of predators to the fish/shellfish farm and control measures	Likely			
20. Litter and debris from farms	Likely	Possible	Possible	Possible
21. Positive effects such as plankton & nutrient removal by shellfish farms	Likely			

Possible
Likely

TABLE 2. CALCULATION OF WEIGHTED SCORE FOR A NOVEL MARICULTURE OPERATION	B MEAN WEIGHTING BY FOUR EXPERTS 1 to 10	C SCORE FOR PROPOSED NOVEL SPECIES 0 to 10	D WEIGHTED SCORE 0 - 100
BIODIVERSITY ISSUE			
1. Availability and sustainability of food	9.0	1	9.0
2. Availability and sustainability of wild broodstock (eggs, larvae, juveniles or adults)	7.5	2	15.0
3. Introduction of genetically modified organisms, either as target species or in food	8.0	1	8.0
4. Genetic intergradation between wild stock and cultivated stock	8.3	3	24.8
5. Escape of fertilised eggs, juveniles and adults	7.5	5	37.5
6. Competition between escaped non-native species and native species	8.8	0	0
7. 'Collateral damage' - escapees sought as food by humans, leading to habitat disturbance	4.0	2	8.0
8. Introduction of veterinary medicines	3.8	0	0.0
9. Reduced water quality due to excretion and respiration	5.0	3	15.0
10. Reduced water quality due to nutrients released and the BOD & COD of the food, faeces & pseudo-faeces whilst in the water column	4.3	3	12.8
11. Reduced sediment quality due to food, faeces and pseudo-faeces falling to seabed	5.0	5	25.0
12. Accidental importation of other species with the target species	7.5	2	15.0
13. Transfer of diseases or parasites from the novel species to local wild or farmed species	8.8	3	26.3
14. Use of antifoulants and other biocides on cages and other structures	4.5	4	18.0
15. Loss of coastal habitats such as wetlands due to production and ancillary facilities	4.5	5	22.5
16. Physical changes to habitat due to aquaculture facilities	2.8	4	11.0
17. Physical smothering of important habitats	4.5	4	18.0
18. Disturbance due to aquaculture operations including harvesting	3.5	5	17.5
19. Attraction of predators to the fish/shellfish farm and control measures	3.3	5	16.3
20. Litter and debris from farms e.g. plastic bags and wrapping	2.8	3	8.3
21. Positive effects such as plankton & nutrient removal by shellfish farms	-3.5	3	-10.5
			297.3

Overall theoretical maximum score (TMS) is 1130 if all positive scores (Issues 1-20) = 10.

Score expressed as a percentage of the theoretical maximum = 26.3%

Biodiversity Risk = Medium