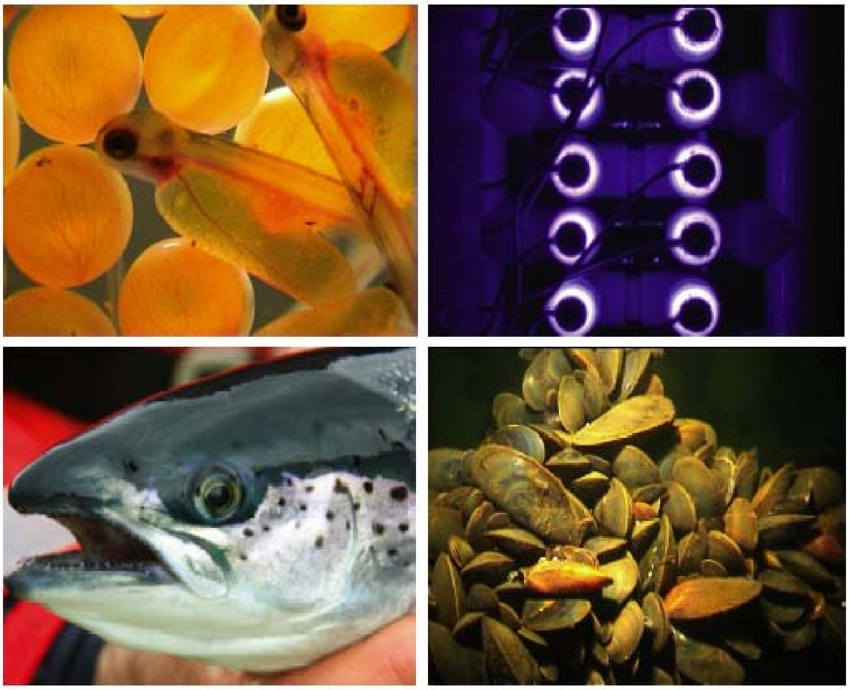
Scottish Aquaculture Research Forum

A Review And Assessment Of The Effects Of Marine Fish Farm Discharges On Biodiversity Action Plan Habitats

SARF036



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AND PREPARED BY

Dr Tom Wilding
Scottish Association for Marine Science

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Executive Summary

The objective of SARF036 was to determine the nature and likely sensitivity of benthic habitats found around Scottish salmon farms and, once identified, assess those habitats (and associated biota) considered to be at greatest risk. The focus was on Biodiversity Action Plan (BAP) habitats and associated megafauna notably seapens. There was particular interest in comparing the output from the model DEPOMOD, which predicts changes in macrofaunal assemblages around salmon farms, with changes in observed megafaunal assemblages.

In order to address this objective, three research phases were conducted. These were:
Phase 1: To conduct a comprehensive review of what is known about the impacts of salmon farming on BAP habitats and associated biota.
Phase 2: To construct a geographical information system (GIS) database that combines existing habitat databases and interrogate it, together with an examination of other data sources, to determine the extent of the overlap between salmon farms and BAP habitats.
Phase 3: To establish the relationship between changes in megafaunal community associated with salmon farms and link with modelled macrofaunal impacts and farm-induced changes in sediment characteristics.

Summary of findings.
Phase 1
All relevant BAP habitats were assessed in terms of their likely sensitivity to salmon farming activities. These habitats ranged between shallow-water seagrass beds to deep-water muds. The sensitivity of different habitats was assessed on the basis of intolerance to smothering and changes in oxygenation and in terms of their recoverability. Habitats deemed highly sensitive included maerl, seagrass and *Sabellaria* /oyster reefs with serpulid reefs, muds in deep water and sheltered muddy gravels being considered moderately sensitive. The degree of overlap between each habitat type and salmon farming was evaluated (as part of Phase 2) to generate a measure of risk.

Phase 2.
Eight data layers were used in the assessment of the ground/habitat type that most closely characterised salmon farm sites.

Sediments around Scottish salmon farms consisted, predominantly, of muds or muddy-sands. These sediments were biologically active (indicated by the predominance of shells in samples) and typically overlain by water >20 m in depth. Salmon farm sites are relatively sheltered and frequently in close proximity (though not necessarily directly over) the bed-type ‘rock’. Approximately 20% of salmon farms are <50 m from records of *Funiculina quadrangularis* whilst 30% are within 50 m of records of *Pennatula phosphorea* and/or *Virgularia mirabilis*. Approximately 20% of salmon farms are found in close proximity (<50 m) to records of *Modiolus modiolus*.

The overall picture is commensurate with the Scottish salmon farm industry being located relatively close to the sides of sheltered sea-lochs over relatively fine sediments that are typically beyond the photic zone.

Habitat risk is a function of sensitivity and overlap. The habitats considered at greatest risk were maerl, mud in deep water, sheltered muddy gravels and beds of *Modiolus modiolus* on the basis of a high degree of spatial overlap with salmon farms and high habitat sensitivity (or lack of knowledge regarding sensitivity). The research presented here (Phase 3) focuses on the risk to the mud in deep water BAP particularly in relation to associated megafauna where our understanding of the interaction is poor.

Phase 3
A drop-down camera was used to observe megafauna along approximately 90 transects around three salmon farms. Sediment samples from matching locations were taken and analysed for loss-on-ignition at 250 C and 500 C (indicative of labile and non-labile organic carbon respectively) and particle size. The sample locations were then matched with their corresponding DEPOMOD predicted ITI. From the video transects 20 species of megafauna and evidence of megafauna (burrows) were enumerated. The megafauna were split into two broad classifications, sensitive species (which included suspension-feeders and burrow counts) and predator/scavengers. The objective was to determine the nature of any relationship between the observed megafauna (density or score) and DEPOMOD predicted ITI and sediment characteristics.

Salmon farms cause a significant reduction in the abundance of megafauna in their immediate vicinity. At the cage edge (corresponding to an ITI of 0 to 5) there were no megafauna. However, further from the cage (ITI of 5 – 15) the numbers of predator/scavengers increased, possibly being attracted to organic detritus as a source of food. Suspension-feeders and burrowing megafauna were negatively associated with farm proximity (as measured by ITI) but there was considerable variability in this proximity effect. We found evidence that sensitive species will be rare to occasional at an ITI of 0 – 20 and (approximately) common to frequent at sites where the ITI is >50. Beyond an ITI of 0 – 5 there were no observed step-changes in megafaunal assemblage. DEPOMOD predictions of ITI were linked to the enrichment of sediments with labile organic material (probably derived from faecal material), a potential driver of the observed changes in megafaunal community.

The impact of salmon farms on the megafauna associated with deep-water muds did not appear extensive and there was no obvious evidence that, in respect of sensitive species, it extended beyond the DEPOMOD predicted ITI 30 contour. It should be noted, however, that our research also indicates that megafauna are not, on their own, a particularly sensitive or useful indicator of the impacts of salmon farms on the benthic environment.

Knowledge gaps and options for further research
This research highlighted some important knowledge gaps concerning the environmental consequences of salmon farming. In respect to megafauna specifically these aspects should take priority in further research (points (a) and (b)) and could, at least in part, be addressed by implementation of point (c).
(a) The extent to which rocky habitats overlap with salmon farms should be further investigated.
(b) Further research into the chronic and acute effects of salmon farms, on seapens and Modiolus modiolus, should be investigated. This should be done through a controlled transplantation experiments and include measures of fitness and/or stress. In the case of M. modiolus this should be accompanied by an assessment of any associated biodiversity change.
(c) We recommend the standardisation of existing statutory reporting from industry to SEPA. Such a standardisation would increase the research value of future observations made by salmon farmers in regulatory compliance and incur no additional cost.

The following, more general concerns should also be addressed:
(a) The fate and behaviour of metals released via salmon farms, the degree of uptake by marine organisms and the potential for biomagnification up the food chain needs further investigation
(b) The potential for acoustic methods of mapping the distribution of sediments and features (e.g. burrows) around salmon farms should be evaluated.

SARF036: A review and assessment of the effects of marine fish farm discharges on Biodiversity Action Plan habitats

Tom Wilding and David Hughes
Scottish Association for Marine Science
Scottish Marine Institute
OBAN
Argyll. PA37 1QA
United Kingdom.

Contents

List of Tables

List of Figures

Scientific objectives as set out in the contract

SARF 036 'A review and assessment of the effects of marine salmon farm discharges on Biodiversity Action Plan habitats' was split into three separate phases.

Phase 1. To produce a comprehensive literature review to consider both published and 'grey' sources viz. the impacts of salmon farming on BAP habitats.
Phase 2. To construct a ArcGIS database that combines existing habitat databases. Interogate the database to determine the most commonly occurring interaction between salmon farms and BAPS.
Phase 3. To establish and explain the relationship between salmon farm distance and megafaunal abundance, in deep-water muddy habitats, with a focus on seapens, anemones and burrowing crustaceans.

1 Phase 1 – Review of impacts of salmon farming on BAP habitats

As a consultee under Environmental Impact Assessment (EIA) (salmon farming in marine waters) Regulations 1999, The Water Environment (Controlled Activities) (Scotland) Regulations 2005, The Coastal Protection Act (1949), Zetland County Council Act 1974, Orkney County Council Act 1974 and the Conservation (Natural Habitats etc.) Regulations 1994, Scottish Natural Heritage (SNH) is required to provide advice to the Scottish Environmental Protection Agency (SEPA), The Crown Estate (CE), Local Authorities and Harbour Authorities on the potential natural heritage impacts of proposed salmon farms, including their possible impact on habitats and species identified in the UK Biodiversity Action Plan (UKBAP), notably those listed as 'priority habitats and species'.

Under section 1(1) of the Nature Conservation (Scotland) Act 2004, the Local Authorities (and a range of other statutory bodies such as CE and SEPA) also have a duty to further the conservation of biodiversity, a responsibility which must be exercised when considering applications for developments such as salmon farms.

The aim of Phase 1 is to provide user-friendly and informed guidance for SNH and these other authorities that will help them to respond authoritatively to such proposals so as to help identify and consequently avoid or minimise any damaging impacts to priority BAP habitats.

1.1 Sources of information

The sensitivity of BAP habitats was assessed by reference to the following sources:
- published Action Plans for the individual UKBAP habitats (http://www/ukbap.org.uk/habitats.aspx)
- MarLIN Biology and Sensitivity Key Information reviews for specific biotopes associated with the relevant UKBAP habitats (http://www.marlin.ac.uk/sah /biotope_information.php)

The rationale for selection of information from these reviews is presented in Sections 1.2).

1.2 MarLIN sensitivity assessment rationale

Full details of the assessment rationale are available from the MarLIN website (http://www.marlin.ac.uk/sensitivityrationale.php), and only a brief summary is presented here. The MarLIN system rates the overall sensitivity of specified biotopes according to the known or predicted responses of one or more indicator species characteristic of that biotope. Indicator species are rated for degree of intolerance with respect to 'benchmarks' of specified magnitudes and directions of change in 24 separate environmental factors (13 physical, 7 chemical and 4 biological factors). Species are also rated for degree of recoverability from environmental changes, according to a scale determined by speed and extent of return to the state prevailing before the specified change.

'Intolerance' is the susceptibility of a habitat, community or species (i.e. the components of a biotope) to damage, or death, from an external factor. Intolerance must be assessed relative to change in a specific factor.

'Recoverability' is the ability of a habitat, community, or species (i.e. the components of a biotope) to return to a state close to that which existed before the activity or event caused change.

Species sensitivity is determined according to the various possible permutations of intolerance and recoverability and is dependent on the intolerance of a species or habitat to damage from an external factor and the time taken for its subsequent recovery. For example, a very sensitive species or habitat is one that is very adversely affected by an external factor arising from human activities or natural events (killed/destroyed, 'high' intolerance) and is expected to recover over a very long period of time, i.e. >10 or up to 25 years ('low'; recoverability). Intolerance and hence sensitivity must be assessed relative to change in a specific factor.

Only a subset of the 24 environmental factors considered in the MarLIN assessment are relevant to this review, which focuses on the effects of discharges from marine salmon farms. Section 1.3 briefly lists the main categories of salmon farm discharges and summarizes the current state of knowledge of their environmental impacts.

1.3 Marine salmon farm discharges and their environmental impacts

Since the establishment of the salmon farming industry in Scotland during the 1970s, it has been clear that cage aquaculture has a range of actual or potential impacts on the marine environment. The environmental impacts of aquaculture have been widely researched and frequently reviewed (Gowen and Bradbury 1987; Munday et al. 1994; Wu 1995; Black 1998). As carried out in Scotland, fish cage aquaculture involves the discharge of several categories of waste material (either solid or dissolved) into the surrounding environment (Pearson and Black 2001). These are described below, with a brief summary of current opinion regarding their effects on the benthic environment.

1.3.1 Particulate organic waste

Fish faeces and uneaten food pellets settle to the seabed below fish cages, with some lateral dispersal of particles dependent on local hydrodynamics (Cromey et al. 2002a). Heavy sedimentation of organic-rich particles has profound effects on the benthic environment, similar to those observed around sewage outfalls and other point sources of organic pollution. Recorded effects include deoxygenation of sediments and overlying water, increased sulphate reduction leading to high levels of hydrogen sulphide in the sediment, and marked changes in species diversity, abundance and biomass of benthic fauna. Impacts around fish cages follow the classic pattern described by Pearson and Rosenberg (1978), and since confirmed by many later studies (e.g. Brown et al. 1987; Weston 1990; Nickell et al. 2003; Kutti et al. 2007). Macrofaunal communities in ‘natural’ (i.e. unimpacted) sediments are typically species-rich, have a relatively low total abundance/species richness ratio, and include a wide range of size classes and functional types. Moderate organic enrichment can act to enhance diversity by providing additional food resources. However, at higher levels of enrichment physical and chemical changes in the sediment progressively eliminate the larger, deep-burrowing species and favour smaller, faster-growing forms living close to the sediment-water interface. Highly-polluted sediments support an abundant, but low-diversity fauna of ‘enrichment opportunists’, typically nematodes and small polychaetes. Species of the genus *Capitella* are particularly characteristic of the latter group. At extreme levels of organic enrichment deoxygenation of the sediment excludes all macrobenthic fauna, and the sediment surface may be covered by mats of sulphide-oxidizing bacteria (*Beggiatoa* sp.). A gradient of communities in successional stages of enrichment is typically found around a point source of organic pollution such as a salmon farm.

The effects of organic enrichment on benthic macrofauna are the most intensively-studied and best-understood environmental impacts of aquaculture, and are clearly relevant to the issue of impacts on UKBAP habitats.

1.3.2 Dissolved nutrients

Fish cages release dissolved compounds directly into the surrounding water column. Soluble waste includes ammonia, nitrate and phosphate together with dissolved organic carbon (DOC). Sources include fish excretory products and dissolution from feed pellets or faecal particles. Nutrient enrichment of the water column can potentially lead to eutrophication, defined by the EU as "*The enrichment of water by nutrients especially compounds of nitrogen and phosphorus, causing an accelerated growth of algae and higher forms of plant life to produce an undesirable disturbance to the balance of organisms and the quality of the water concerned*". Concerns have been expressed that nutrient release from salmon farms in Scotland has led to an increased occurrence of algal blooms, and has disturbed the natural nutrient ratios in seawater favouring the growth of toxic species responsible for harmful algal blooms (HABs) (Berry 1996). However, the current consensus is that enrichment by salmon farm nutrients is generally too little, relative to natural levels, to have the alleged effects (SAMS and Napier_University 2002). A recent modelling study of Loch Creran, Argyll, found that an increased nutrient input from salmon farms over the 1975-2003 period did not result in a signficant increase in nutrient concentrations in the loch (Laurent et al. 2006). Observed chlorophyll concentrations decreased substantially over the study period, in contrast to the predictions of the eutrophication hypothesis. In a comprehensive review of the issue, Smayda (2006) found no convincing link between observed HABs in Scottish waters and nutrient release from salmon farms.

In view of the lack of evidence for harmful ecosystem effects of nutrient release from Scottish salmon farms, it is concluded that UKBAP benthic habitats are unlikely to be affected by this form of discharge.

1.3.3 Veterinary medicines and pesticides

Medicines are administered to farmed salmon to treat bacterial infections and reduce parasite load. Antibiotics such as oxytetracycline and amoxycillin are administered in feed and reach the seabed both directly and following egestion. Residues can often be detected in the sediments below farms that have treated fish with antibiotics. There is evidence that antibiotic use in aquaculture can promote the growth of resistant strains of bacteria in seabed sediments (Miranda and Zemelman 2002; Chelossi et al. 2003) but it is highly unlikely that this form of discharge will have any effect on benthic animal or plant life (although nothing is known about the potential effects on bacterial symbionts).

A variety of chemical agents have been used to control infestations of ectoparasitic copepods or 'sea lice' (*Lepeophtheirus salmonis* and *Caligus elongatus*), which are serious pests of farmed salmon. Currently five types of chemotherapeutants are used, or have been proposed for use, in this role (http://www.sepa.org.uk).

All are discharged into the environment after use. The properties of each type are summarized in Table 1.

Table 1 – Summary of the fate and behaviour of chemotheraputants used in/on salmon farms

Compound type	Active ingredient	Product name	Selected properties	Probable environmental fate
Organophosphate	Dichlorvos* Azamethiphos*	Aquagard Salmosan	Water-soluble. No bioaccumulation or biomagnification	Diluted in sea water
Hydrogen peroxide		Salartect Paramove	Degrades rapidly	Degrades rapidly, does not persist
Synthetic pyrethroid	Cypermethrin	Excis	Strongly adsorbed onto sediment particles, low solubility in water. Little tendency to bioaccumulate	Sediment-bound
Avermectin	Ivermectin Emamectin	Ivomec Slice	Low solubility in water. Strong affinity	Sediment-bound

	benzoate		to lipid, soil, organic matter	
Benzamide (Benzoylphenylurea) Insect growth regulators (IGR)	Diflubenzuron** Teflubenzuron	Ektobann Calicide	Low water solubility	Sediment-bound

* - no longer licensed by SEPA
** - only licensed by SEPA on a temporary experimental basis

Hydrogen peroxide, cypermethrin and azamethiphos are administered as bath treatments, with the dissolved medicine being released into the water column after the treatment period. Emamectin benzoate and teflubenzuron are administered in fish feed and therefore accumulate in seabed sediments after deposition of faeces. Of the four synthetic compounds currently licensed for use as sea lice medicines in Scotland, cypermethrin (Excis™) and emamectin benzoate (Slice™) are the most widely-used (SAMS and Napier_University 2002).

The rapid breakdown of hydrogen peroxide to water and oxygen means that it presents no long-term hazard to marine life. In an experimental study of dispersal and toxicity of anti-lice chemicals following bath treatments (Ernst et al. 2001), water samples taken after release of azamethiphos were not toxic beyond 20 minutes post-release, but toxic effects of cypermethrin were detectable for up to 5 hours. It was concluded that cypermethrin bath treatment had the potential to cause toxic effects over a scale of hectares following release into the water column. However, a later 1-year field study found no evidence that zooplankton communities in Loch Sunart were adversely affected by use of cypermethrin and emamectin benzoate at a local salmon farm (Willis et al. 2005). Abundance and community composition displayed natural seasonal cycles and no toxic effects were detected. The common mussel *Mytilus edulis* was found to exhibit a shell-closure response when experimentally exposed to cypermethrin, with some evidence of bioaccumulation (Gowland et al. 2002). However, it was concluded that stress responses were unlikely to occur in the field at the cypermethrin concentrations used in fish cages.

Emamectin benzoate is one of a wide range of compounds known to have endocrine-disruptive effects on aquatic crustaceans (Rodriguez et al. 2007). Large doses of the chemical disrupt the moult cycle of female American lobsters (*Homarus americanus*), causing them to moult prematurely and shed attached eggs (Waddy et al. 2002). However, in laboratory trials lobsters were found to prefer natural food to salmon pellets containing emamectin benzoate, and rapidly became conditioned to reject the medicated feed (Waddy et al. 2002). Similar responses have been described for spot prawns (*Pandalus platyceros*) and Dungeness crabs (*Cancer magister)* (van Aggelen et al. 2003). In a large-scale field trial in Scotland, although emamectin benzoate was detectable in sediments 10 m distant from salmon cages up to 12 months after treatment, declining concentrations over time showed that the chemical was degrading (Telfer et al. 2006). Mussels (*Mytilus edulis*) did accumulate emamectin benzoate immediately after treatment but had largely depurated 1 month later. Faunal analysis provided no evidence that emamectin benzoate in sediments had any toxic effects on benthic communities, a result consistent with the conclusion of Willis et al (2005) from a comparable long-term field study of zooplankton.

A 2002 report to the Scottish Executive (SAMS and Napier_University 2002) concluded that use of cypermethrin might entail some environmental risk, and rated the risk of emamectin benzoate as 'low to moderate'. The consensus from work published since then is that neither compound has been shown to have adverse environmental effects at the concentrations encountered under conditions of typical use at salmon farms. However, it would be premature to conclude that chemotherapeutants will have no effects on UKBAP habitats as little experimental work has been carried out on the effects of teflubenzuron on non-target marine organisms, but Mendez (2006) found that environmentally-relevant concentrations of the chemical caused mortality in one species of *Capitella* and reduced the egestion rate of another. Teflubenzuron in salmon farm sediments could therefore potentially affect rates of sediment processing by these ecologically-important polychaetes. The anti-parasite compound ivermectin is highly toxic to benthic polychaetes and crustaceans (Black 1998; Collier and Pinn 1998; Grant and Briggs 1998a). This compound is not currently licensed for use in Scotland but there is evidence of occasional unauthorized use (Grant and Briggs 1998b; SEPA 2004). The possibility of synergistic effects of different forms of discharge, and the responses of organisms not yet studied experimentally must also be considered. Ford et al. (2007) found increased levels of intersex in populations of the amphipod *Echinogammarus marinus* from sites in close proximity to salmon farms. No causal relationship with farm discharges was established, but the study demonstrates the need for further research on the responses of non-target organisms in areas used for salmon farming. Consequently, in this review a conservative approach is taken, and chemotherapeutants are regarded as having the potential to affect UKBAP benthic habitats.

1.3.4 Heavy metals

Heavy metals, particularly copper and zinc, can be present at elevated concentrations in salmon farm sediments (Mendiguchia et al. 2006; Dean et al. 2007). The principal sources of these metals are fish feed and antifoulant paints used on fish cages and associated structures. The ecological effects of high metal concentrations in salmon farm sediments are unknown (SAMS and Napier_University 2002) but are likely to depend on the chemical speciation and consequent bioavailability of metals. Organically-enriched salmon farm sediments are typically oxygen-deficient with high rates of sulphate reduction. Under such conditions metals such as copper and zinc are less likely to be biologically available. However, much more research is needed to determine the chemical behaviour of metals in farm sediments, the degree of uptake by marine organisms and the potential for biomagnification up the food chain. For the purpose of this review, the same conservative approach is applied to heavy metals as previously used in relation to anti-parasite treatments. There is considered to be some potential for toxicity affecting UKBAP benthic habitats.

1.4 Salmon farm discharges in relation to MarLIN sensitivity assessments

The following factors used in the MarLIN scheme for Sensitivity Assessment are considered applicable to the effects of salmon farm discharges. The MarLIN factors are rated for level of effect against specified ‘benchmarks’ (http://www.marlin.ac.uk/sah/baskitemplate.php?benchmarks), listed below.

1.4.1 Smothering

Benchmark: ‘*All of the population of a species or an area of a biotope is smothered by sediment to a depth of 5 cm above the substratum for one month’*. Continuous deposition of fish faeces and uneaten food beneath fish cages is considered to meet the definition used for this factor.

1.4.2 Changes in levels of synthetic chemicals

The Benchmarks refer to mass mortality (High Sensitivity), reduced population abundance or extent (Intermediate Sensitivity) and sublethal effects/reduced reproductive potential (Low Sensitivity). The ‘Synthetic Chemicals’ category is applicable to the chemotherapeutants discussed above, as well as to anti-foulant chemicals such as tributyltins (TBT). The same benchmarks are used for changes in levels of heavy metals.

1.4.3 Changes in oxygenation

Benchmark: *‘Exposure to a dissolved oxygen concentration of 2 mg l^{-1} for one week’.* The benchmark cannot be applied precisely in this exercise, as oxygen concentration data for sediments and near-bed water column under salmon farms are not always available, and are likely to depend on farm-specific factors such as local hydrodynamics and organic loading. Nevertheless, the factor is considered relevant in view of the deoxygenation that typically occurs as a result of the high organic loading beneath fish cages.

1.5 Sensitivity of UKBAP benthic habitats to salmon farm discharges

For each habitat, the following information is presented;

- Brief habitat description
- JNCC biotopes included in habitat (from 2004 Habitat Classification, ver. 04.05, http://www.jncc.gov.uk/marine/biotopes/)
- General distribution of habitat in Scotland
- Known or likely occurrence in areas used for salmon farming
- Biotope(s) used in MarLIN Sensitivity Assessment, with indicator species
- MarLIN Sensitivity Assessment for relevant factors listed in Section 6 above
- Explanation of Sensitivity and Recoverability ratings (paraphrased from MarLIN Sensitivity Assessment rationale, which should be consulted for full details)
- Conclusion (including any relevant information not available to MarLIN when compiling the Sensitivity Assessment).

1.5.1 Maerl beds

Habitat description
The term 'maerl' refers to calcareous red algae growing as free-living, unattached nodules, often in extensive beds. Several red algal species can occur in this growth form. Beds are typically found at shallow depths (< 20 m) in areas sheltered from wave action but exposed to vigorous tidal streams. Maerl beds support a rich associated biota of epiphytic algae and small invertebrates.

JNCC biotopes included in habitat
The current JNCC classification (ver. 04.05) includes five biotopes within the broad category of Maerl beds:

1. SS.SMp.Mrl.Pcal.R, *Phymatolithon calcareum maerl beds with red seaweeds in shallow infralittoral clean gravel or coarse sand*

2. SS.SMp.Mrl.Pcal.Nmix, *Phymatolithon calcareum maerl beds with Neopentadactyla mixta and other echinoderms in deeper infralittoral clean gravel or coarse sand*

3. SS.SMp.Mrl.Lcor, *Lithothamnion coralloides maerl beds on infralittoral muddy gravel*

4. SS.SMp.Mrl.Lgla, *Lithothamnion glaciale maerl beds in tide-swept variable salinity infralittoral gravel*

5. SS.SMp.Mrl.Lfas, *Lithophyllum fasciculatum maerl beds on infralittoral mud*

Distribution in Scotland
Biotope 5 in the list above is known only from south-west Ireland and has no Scottish records. The remaining four occur at sites along the Scottish west coast, the Inner and Outer Hebrides, Orkney and Shetland. Beds are entirely absent from the east coast of Scotland. *Phymatolithon calcareum* maerl beds (Biotopes 1 and 2) are the most common and widespread form in Scotland, with beds of *Lithothamnion* spp. (Biotopes 3 and 4) being much less common.

Occurrence in areas used for salmon farming
The required habitat conditions of shallow water, shelter and strong tidal flow are typical of coastal topographic constrictions such as sea loch entrance channels, tidal rapids and straits. The distribution along the west coast and around the northern and western islands of Scotland coincides with the geographic focus of the salmon farming industry.

Biotope and indicator species used in Sensitivity Assessment
MarLIN Sensitivity Assessments have been compiled for Biotopes 2 and 4 listed above, based on information for the following indicator species:

SS.SMp.Mrl.Pcal.Nmix
- Key structural species: *Phymatolithon calcareum* (Rhodophyta)

- Important characterizing species: *Nemertesia ramosa* (Hydrozoa), *Neopentadactyla mixta* (Holothuroidea)

SS.SMp.Mrl.Lgla
- Key structural species: *Lithothamnion glaciale* (Rhodophyta)
- Important functional species: *Ophiothrix fragilis* (Ophiuroidea), *Psammechinus miliaris* (Echinoidea)

Table 2 - MarLIN Sensitivity Assessment for Maerl beds

Factor	Intolerance	Recoverability	Sensitivity	Effect on species richness	Evidence/ Confidence
Smothering					
• Pcal.Nmix	High	Very low	Very high	Major decline	High
• Lgla	High	Very low	Very high	Major decline	High
Synthetic compounds					
• Pcal.Nmix	Insufficient information	Insufficient information	Insufficient information	Insufficient information	Not relevant
• Lgla	High	High	Moderate	Decline	Very low
Heavy metals					
• Pcal.Nmix	Insufficient information	Insufficient information	Insufficient information	Insufficient information	Not relevant
• Lgla	Insufficient information	Not relevant	Insufficient information	Not relevant	Not relevant
Changes in oxygenation					
• Pcal.Nmix	High	Very low	Very high	Major decline	Low
• Lgla	Intermediate	Moderate	Moderate	Major decline	Very low

Explanation
As plants dependent upon photosynthesis, the key structural species of the maerl biotopes – the maerl algae themselves – will be highly sensitive to smothering. Heavy deposition of sediment or organic farm waste will therefore have severe impacts on the health and survival of the maerl. Deposited waste will also fill the interstices between the maerl nodules and thereby damage the associated invertebrate community. Both biotopes are regarded as being sensitive to deoxygenation, a factor which would normally accompany the deposition of organic waste from a salmon farm. Little information is available to assess the sensitivity of maerl to synthetic compound or heavy metal contamination. The rating of 'Moderate' sensitivity to synthetic compounds assigned to the *Lithothamnion glaciale* biotope is based on the responses of associated echnoderm and mollusc species to chemical contamination (type unspecified).

Conclusion
Since the compilation of the MarLIN Sensitivity Assessments summarized above, several papers have been published dealing with the environmental tolerances of maerl and the observed impacts of salmon farming on maerl biotopes. Wilson et al (2004) carried out laboratory experiments on physiological tolerances of *Phymatolithon calcareum.* The species was found to be quite tolerant of heavy metal contaminants, but burial, especially in fine or anoxic sediments, was lethal or caused signficant stress. Hall-Spencer et al (2006) have recently demonstrated that salmon farm discharges have major impacts on maerl beds, even in strongly tidal areas. Diving surveys around three salmon farms located over maerl beds in Orkney, Shetland and South Uist found accumulations of organic

waste, reductions in live maerl cover and enhanced abundance of scavenging crustaceans, relative to conditions at reference sites away from salmon farms. Visible waste was noted up to 100 m distant from cage edges. Near-cage infaunal samples showed signficant reductions in biodiversity of small crustaceans, and increased abundance of opportunistic polychaete species typical of organically-enriched environments. Overall, it was concluded that the strong tidal currents often associated with maerl biotopes are unlikely to prevent significant detrimental effects of organic waste deposition. Impacts of organic waste deposition on the crustacean fauna of maerl beds are possibly compounded by the effects of sea-lice treatments (Hall-Spencer and Bamber 2007).

These three recent studies support the main conclusion of the MarLIN Sensitivity Assessments, namely that maerl beds are highly susceptible to the effects of particulate waste deposition from salmon farms. High organic loading results in the long-term loss of living maerl, and much of the associated invertebrate fauna is also highly intolerant of smothering by organic waste.

1.5.2 Seagrass beds

Habitat description
Seagrass beds grow on sandy or muddy substrata in intertidal and shallow subtidal waters sheltered from wave action. Typical locations include enclosed inlets and bays, lagoons and channels. In the UK, three species of eelgrass occur. *Zostera noltii* is found highest on the shore, *Z. angustifolia* on the mid to lower shore, and *Z. marina* mainly in the shallow subtidal. The tasselweeds *Ruppia maritima* and *R. cirrhosa* are found in extremely sheltered, often brackish muddy lagoons and inlets. All types of seagrass bed support an associated community of algae, invertebrates and fish.

JNCC biotopes included in habitat
Three seagrass biotopes are defined in the current (ver. 04.05) version of the JNCC habitat classification:

1. LS.LMp.LSgr.Znol, *Zostera noltii beds in littoral muddy sand*
2. SS.SMp.SSgr.Zmar, *Zostera marina/angustifolia beds on lower shore or infralittoral clean or muddy sand*
3. SS.SMp.SSgr.Rup, *Ruppia maritima beds in reduced salinity infralittoral muddy sand*

Distribution in Scotland
In Scotland, *Zostera noltii* beds are best-developed on the east coast, particularly in the Moray and Cromarty Firths. There are also several examples in the Solway Firth but only a few on the west coast and Outer Hebrides. In contrast, the distribution of *Z. marina* beds is centred on the west coast, extending to the Outer Hebrides, Orkney and Shetland. *Ruppia* spp. are found mainly in the Outer Hebrides, Orkney and Shetland with a smaller number of localities on the mainland west coast.

Occurrence in areas used for salmon farming
The predominantly east coast distribution of *Z. noltii* means that there is little overlap with salmon farming activity. The potential for interaction is greatest for *Z. marina*, which has many records from the upper reaches of west coast sea lochs which are also the main areas used for aquaculture. Lagoons and inlets supporting *Ruppia* beds may also form part of sea loch or fjardic systems used for salmon farming in the western and northern isles.

Biotope and indicator species used in Sensitivity Assessment
MarLIN Sensitivity Assessments have been prepared for all three seagrass biotopes, based on the following indicator species:

LS.LMp.LSgr.Znol
- Key structural species: *Zostera noltii*
- Important functional species: *Hydrobia ulvae, Littorina littorea* (both Gastropoda)
- Important other species: *Cerastoderma edule* (Bivalvia), *Arenicola marina* (Polychaeta)

SS.SMp.SSgr.Zmar
- Key structural species: *Zostera marina*
- Important structural species: *Lacuna vincta, Hydrobia ulvae* (both Gastropoda)

SS.SMp.SSgr.Rup

- Key structural species: *Ruppia maritima, R. cirrhosa*
- Important fucntional species: *Hydrobia ulvae* (Gastropoda), *Gammarus* spp. (Amphipoda)
- Important other species: *Cerastoderma glaucum* (Bivalvia), *Arenicola marina* (Polychaeta), *Potamoschistus minutus* (Osteichthyes)

Table 3 - MarLIN Sensitivity Assessment for Seagrass beds

Factor	Intolerance	Recoverability	Sensitivity	Effect on species richness	Evidence/ Confidence
Smothering					
• Znol	High	Low	High	Major decline	Moderate
• Zmar	High	Very low	Very high	Major decline	Moderate
• Rup	Intermediate	Very high	Low	Decline	Low
Synthetic compounds					
• Znol	Intermediate	Moderate	Moderate	Minor decline	Low
• Zmar	Intermediate	Moderate	Moderate	Decline	Moderate
• Rup	High	Moderate	Moderate	Major decline	Moderate
Heavy metals					
• Znol	Intermediate	Very high	Low	Minor decline	Moderate
• Zmar	Low	High	Low	No change	Low
• Rup	Low	Very high	Very low	Decline	Very low
Changes in oxygenation					
• Znol	Intermediate	High	Low	Minor decline	Low
• Zmar	Intermediate	High	Low	Minor decline	Low
• Rup	Low	Very high	Very low	Decline	Low

Explanation
Zostera spp. are known to be highly intolerant of smothering. The grass blades are bent over and buried by the addition of a few centimetres of sediment. Surface-dwelling epifauna are also adversely affected by sediment deposition, burrowing infauna less so. In contrast, *Ruppia* spp. and their associated fauna are considered to be rather more resilient to this form of stress. A sensitivity rating of 'Moderate' for synthetic compound contamination is based on the known effects of compounds such

as TBT on gastropod and bivalve species. *Zostera marina* is known to accumulate TBT and heavy metals but no direct harmful effects have been recorded. However, some members of the invertebrate communities associated with seagrass beds may be more adversely affected by heavy metal contamination. *Zostera* spp. are probably more susceptible to stress from hypoxia than *Ruppia* spp., which typically occur in quiescent lagoons with low water exchange and lower ambient dissolved oxygen concentrations.

Conclusions
The MarLIN assessments suggest that seagrass beds directly beneath or in close proximity to fish cages will be seriously impacted by deposition of solid organic waste. This conclusion is most relevant to subtidal *Zostera marina* beds. Beds of *Z. noltii* or *Ruppia* spp. growing in the intertidal zone or in very shallow infralittoral environments are less likely to be in close proximity to fish cages. These biotopes also have less geographic overlap with areas used for salmon farming.

Over the past decade, a considerable amount of research has been conducted on the impacts of salmon farming on subtidal seagrass beds (mainly *Posidonia oceanica*) in the Mediterranean. These studies, reviewed by Pergent-Martini et al (2006) confirm that organic waste deposition has severe impacts on seagrass, and therefore broadly support the conclusion of the MarLIN assessments. Mediterranean studies are consistent in showing that *Posidonia oceanica* disappears directly beneath fish cages, while surrounding beds are significantly degraded (Delgado et al. 1997; Ruiz et al. 2001). Deterioration of seagrass beds may continue even after cessation of salmon farming activity (Delgado et al. 1999). *Posidonia* plants growing near fish cages display growth abnormalities and carbon budget imbalances indicative of physiological stress (Cancemi et al. 2003; Marba et al. 2006). The critical factor causing impacts appears to be solid waste deposition and the consequent high organic loading and deoxygenation of sediments. Nutrient enrichment of the water column can also lead to proliferation of epiphytic algae which reduce the photosynthetic ability of the seagrasses (Cancemi et al. 2003). Little information is available on impacts to the biota associated with seagrass beds. At three Mediterranean sites, macrofaunal biomass peaked at an intermediate distance from the fish cages and diversity remained quite high, indicative of only moderate environmental impact (Apostolaki et al. 2007). However, all three sites were characterized by strong currents and relatively coarse sediments, and greater impacts could be expected in lower-energy conditions.

There are clearly differences in environmental conditions between the Mediterranean and Scottish salmon farming localities which necessitate caution in applying the findings from one area to the other. Nutrient enrichment and eutrophication are likely to be less important in Scottish waters than in the oligotrophic Mediterranean environment. However, the general conclusion that subtidal seagrasses are highly intolerant of solid organic waste deposition is likely to apply to Scottish *Zostera marina* beds.

1.5.3 Serpulid reefs

Habitat description
Large clumps of the calcareous tubes of *Serpula vermicularis,* typically attached to stones or shells in muddy sediment in very sheltered conditions in sea lochs. Rich associated biota of algae and sessile invertebrates. Used as habitat by fish and mobile invertebrates (Poloczanska et al. 2004).

JNCC biotopes included in habitat
The habitat is defined by the single biotope SS.SBR.PoR.Ser, *Serpula vermicularis reefs on very sheltered circalittoral muddy sand.*

Distribution in Scotland
Currently known only from Loch Creran, north Argyll. Fomerly occurred in Linne Mhuirich, an arm of Loch Sween, mid Argyll, but reefs there had died out by 1994 and have not recovered since (Hughes et al. 2008).

Occurrence in areas used for salmon farming
Loch Creran is the site of a substantial salmon farm (Nickell et al. 2003; Laurent et al. 2006).

Biotope and indicator species used in Sensitivity Assessment
The nominate biotope is used, with the single indicator species *Serpula vermicularis* (Key structural species).

Table 4 - MarLIN Sensitivity Assessment for *Serpulid* reefs

Factor	Intolerance	Recoverability	Sensitivity	Effect on species richness	Evidence/ Confidence
Smothering	Intermediate	High	Low	Decline	Moderate
Synthetic compounds	Insufficient information	Insufficient information	Insufficient information	Insufficient information	Not relevant
Heavy metals	Low	Insufficient information	Insufficient information	Insufficient information	Not relevant
Changes in oxygenation	Intermediate	High	Low	Minor decline	Moderate

Explanation
Intolerance to smothering is rated as 'Intermediate' on the grounds that deposited sediment will accumulate in the interstices of the reef structure, blanketing some of the tubeworms and associated sessile invertebrates. Deposited sediment on exposed surfaces may also inhibit larval settlement. Recoverability is rated as 'High' on the grounds that elevated surfaces (upright tubes) will remain free of sediment and available for colonization by larvae.

No relevant information was found on the sensitivity of *S. vermicularis* to synthetic compounds. In the MarLIN rationale, a reference to the presence of the species in the Fal Estuary, Cornwall, exposed to high metal concentrations, is used to assign a 'Low' rating for intolerance to this factor.

The lower depth limit of *S. vermicularis* growth in Ardbear Lough, Ireland, is considered to be a possible consequence of sensitivity to oxygen-poor bottom water, leading to a rating of 'Intermediate' for intolerance to this factor.

Conclusion
The salmon farm in Loch Creran is currently located roughly in mid-loch (Nickell et al. 2003; Laurent et al. 2006). Some distance from the shallow peripheral zone which provides the habitat for serpulid reefs. As a result there will be no direct impact on the reefs from organic deposition or bottom-water deoxygenation. Moore (1996) reported that salmon cages moored at that time in a bay along the northern side of the loch appeared to have no obvious adverse impact on reef distribution or abundance.

As outlined previously, there is little evidence that the chemotherapeutants commonly-used on Scottish salmon farms have any adverse effects on benthic organisms. This, together with the current spatial location of the salmon farm in Loch Creran, suggest that discharges from aquaculture are unlikely to significantly impact the *S. vermicularis* reefs.

1.5.4 *Sabellaria* reefs

Habitat description
Thick crusts of tightly-packed sand-grain tubes built by sabellariid polychaetes in the low intertidal (usually *Sabellaria alveolata*) or shallow subtidal (usually *S. spinulosa*). Can be found on gravel, pebble, cobble or bedrock substrata. Typically provide habitat for a rich associated biota of small invertebrates.

JNCC biotopes included in habitat
Seven biotopes characterized by *Sabellaria* reefs/crusts are currently recognized:

1. LS.LBR.Sab.Salv, *S. alveolata reefs on sand-abraded eulittoral rock*
2. SS.SBR.PoR.SalvMx, *S.alveolata on variable salinity sublittoral mixed sediment*

3. IR.MIR.KR.Lhyp.Sab, *S. spinulosa with kelp and red seaweeds on sand-influenced infralittoral rock*
4. CR.MCR.Csab.Sspi, *S. spinulosa-encrusted circalittoral rock*
5. CR.MCR.Csab.Sspi.ByB, *S. spinulosa with a bryozoan turf and barnacles on silty turbid circalittoral rock*
6. CR.MCR.Csab.Sspi.As, *S. spinulosa, didemnids and other small ascidians on tide-swept, moderately wave-exposed circalittoral rock*
7. SS.SBR.PoR.SspiMx, *S. spinulosa on stable circalittoral mixed sediment*

Distribution in Scotland
Occurrence in Scotland is very limited. Biotopes 2, 3, 5, 6 and 7 listed above have no Scottish records. Biotope 1 occurs along the northern coast of the Solway Firth as far west as Luce Bay. Biotope 4 has a record off Burrow Head (Solway Firth) and is also found along the North Northumberland coast, possibly extending into Berwickshire.

Occurrence in areas used for salmon farming
None. There are no records of *Sabellaria* biotopes from the Clyde or west coast sea lochs, the Western Isles, Orkney or Shetland. The habitat requirements and often conspicuous appearance of *Sabellaria* reefs mean that absence from these areas can be regarded as genuine and not the result of under-recording.

Sensitivity Assessment
MarLIN Sensitivity Assessments have been compiled for three of the *Sabellaria* biotopes listed above (Numbers 1, 3, 4) and can be accessed on the MarLIN website. Owing to the complete absence of these biotopes from areas used by the Scottish salmon farming industry it is not necessary to discuss them further in this review.

1.5.5 Mud habitats in deep water

Habitat description
Plains of fine mud at depths >15 m, characterized by sea pens (pennatulaceans) and a conspicuous seabed topography of mounds, pits and holes created by large deep-burrowing invertebrates (and some fish species). Burrowing megafauna include the commercially-valuable Norway lobster *Nephrops norvegicus*, the mud-shrimp *Callianassa subterranea* and the echiuran worm *Maxmuelleria lankesteri* (Hughes, 1998).

JNCC biotopes included in habitat
The habitat category is interpreted in broad terms to cover soft-sediment biotopes having sea pens and/or burrowing megafauna, including examples having only one of these two groups. The biotope complex also includes examples that occur in shallower water, or in slightly coarser sandy mud sediments than stated in the UKBAP habitat definition. Using these criteria the current list is as follows:

1. SS.Smu.CfiMu.SpnMeg, *Sea pens and burrowing megafauna in circalittoral fine mud*
2. SS.Smu.CfiMu.SpnMeg.Fun, *Sea pens, including Funiculina quadrangularis, and burrowing megafauna in circalittoral fine mud*
3. SS.Smu.CfiMu.MegMax, *Burrowing megafauna and Maxmuelleria lankesteri in circalittoral mud*
4. SS.Smu.CfiMu.BlyrAchi, *Brissopsis lyrifera and Amphiura chiaijei in circalittoral mud*
5. SS.Smu.IfiMu.PhiVir, *Philine aperta and Virgularia mirabilis in soft stable infralittoral mud*
6. SS.Smu.CSaMu.VirOphPmax, *Virgularia mirabilis and Ophiura spp. with Pecten maximus on circalittoral sandy or shelly mud*
7. SS.Smu.CSaMu.VirOphPmax.Has, *Virgularia mirabilis and Ophiura spp. with Pecten maximus, hydroids and ascidians on circalittoral sandy or shelly mud with stones*

Distribution in Scotland
All of the biotopes in this complex are known mainly from Scotland, with only scattered records from elsewhere in the UK. These biotopes are characteristic of the sea lochs in the Clyde Sea and along the west coast, with many additonal records from the Western Isles and a smaller number from

Orkney and Shetland. Biotopes 1, 5, 6 and 7 from the list above are particularly widespread and common.

Occurrence in areas used for salmon farming
Extensive. As a characteristic feature of the sheltered basins of west coast sea lochs, this habitat has a range almost exactly matching the distribution of the Scottish salmon farming industry.

Biotope and indicator species used in Sensitivity Assessment
MarLIN Sensitivity Assessments are available for three of the biotopes occurring in this Habitat, listed below under their current JNCC codes and the previous codes (from ver. 97.04 of the JNCC Habitat Classification) used on the MarLIN website. The species used in assessing sensitivity are also listed.

SS.Smu.CfiMu.SpnMeg (formerly CMU.SpMeg)
- Key functional species: *Callianassa subterranea* (Crustacea)
- Important characterizing species: *Virgularia mirabilis* (Pennatulacea)
- Important functional species: *Amphiura filiformis* (Ophiuroidea), *Liocarcinus depurator* (Crustacea)

SS.Smu.CfiMu.BlyrAchi (formerly CMU.BriAchi)
- Key functional species: *Brissopsis lyrifera* (Echinoidea)
- Important characterizing species: *Amphiura chiajei* (Ophiuroidea)
- Important other species: *Calocaris macandreae, Nephrops norvegicus* (both Crustacea)

SS.Smu.CSaMu.VirOphPmax and SS.Smu.CSaMu.VirOphPmax.Has (formerly combined as CMS.VirOph)
- Important characterizing species: *Virgularia mirabilis* (Pennatulacea), *Amphiura filiformis* (Ophiuroidea)

Table 5 - MarLIN Sensitivity Assessment for mud in deep-water

Factor	Intolerance	Recoverability	Sensitivity	Effect on species richness	Evidence/ Confidence
Smothering • SpnMeg • BriAchi • VirOph	 Low Low Low	 Immediate Immediate Very high	 Not sensitive Not sensitive Very low	 No change No change Minor decline	 High Moderate Moderate
Synthetic compounds • SpnMeg • BriAchi • VirOph	 High High High	 Moderate Moderate High	 Moderate Moderate Moderate	 Decline Decline Minor decline	 Low High Low
Heavy metals • SpnMeg • BriAchi • VirOph	 Intermediate Intermediate Intermediate	 High Moderate High	 Low Moderate Low	 Decline Decline Minor decline	 High Moderate Low
Changes in oxygenation • SpnMeg • BriAchi • VirOph	 Low High Low	 Immediate Moderate Immediate	 Not sensitive Moderate Not sensitive	 Minor decline Decline No change	 Moderate Moderate Low

Explanation
The MarLIN assessments for the different factors are broadly consistent across all three biotopes. Sensitivity to smothering is rated as ‘Very low – Not sensitive’ on the grounds that burrowing species can easily re-open their burrows or move upwards in the sediment in response to surface deposition.

The upright stance of the sea pen species offers some protection against smothering. Sensitivity to synthetic compounds and heavy metals is rated as ‘Low -Moderate’, although very little directly relevant information is available for either factor

These biotopes typically occur in physically quiescent settings such as the deep basins of sea lochs. In such environments dissolved oxygen concentrations may fall well below saturation level. Species adapted to live in these conditions will therefore be tolerant to moderate levels of hypoxia. Megafauna occupying deep burrows are very resistant to oxygen depletion and high sulphide concentrations. The one exception to this generalization is the burrowing urchin *Brissopsis lyrifera,* which is considered to be intolerant of hypoxia. The biotope characterized by this species is therefore given a higher rating for sensitivity to changes in oxygen concentration.

Conclusion
The MarLIN assessments suggest that deep mud biotopes should be relatively tolerant to salmon farm discharges. However, one of the defining features of the Pearson and Rosenberg (1978) model of community responses to organic enrichment is the disappearance of large, deep-burrowing species in conditions of high organic loading, such as occur beneath fish cages. This pattern has been confirmed by a recent study in Loch Creran (Nickell et al. 2003). The likely explanation is that there is a threshold of sedimentation, organic enrichment and associated deoxygenation/sulphide concentration above which even the hardiest species cannot survive. To date there has been no systematic study of the distribution of sea pens or large burrowers around salmon farms and no quantitative value can yet be assigned to this proposed threshold.

There is currently no evidence to suggest that deep mud biotopes suffer any adverse effects from discharges of chemotherapeutants or heavy metals from salmon farms. However, megafaunal burrowers are potentially exposed to high levels of sediment-bound contaminants. The crustacean burrowers (such as *Nephrops norvegicus*, *Callianassa subterranea, Calocaris macandreae*) are the most likely species to be affected by anti-parasite compounds in salmon farm sediments.

1.5.6 Sheltered muddy gravels

Habitat description
Muddy gravels extending from the lower shore to the shallow sublittoral, occurring principally in estuaries and sea lochs sheltered from wave action and strong tidal streams. Habitat supports a diverse invertebrate fauna, with various polychaete and bivalve species being most characteristic.

JNCC biotopes included in habitat
The 2004 Habitat Classification (ver. 04.05) classifies the following four biotopes under this broad habitat definition:

1. SS.SMx.Imx.VsenAsquAps, *Venerupis senegalensis, Amphipholis squamata and Apseudes latreilli in infralittoral mixed sediment*
2. SS.SMx.Imx.SpavSpAn, *Sabella pavonina with sponges and anemones on infralittoral mixed sediment*
3. SS.SMx.Imx.Lim, *Limaria hians beds in tide-swept sublittoral muddy mixed sediment*
4. SS.SMx.Imx.Ost, *Ostrea edulis beds on shallow sublittoral muddy sediment*

The *Limaria hians* and *Ostrea edulis* biotopes are considered separately in Sections 7.9 and 7.10 of this review. Further discussion in this Section refers to Biotopes 1 and 2 of the list above.

Distribution in Scotland
Biotopes 1 and 2 are both uncommon in Scotland. Biotope 1 has three possible records from the mainland west coast and two more from the Western Isles.. Biotope 2 has four records from Argyll, one from Orkney and one from the Western Isles.

Occurrence in areas used for salmon farming
In Scotland the habitat conditions supporting these biotopes are most likely to occur in sea lochs and there is consequently some potential overlap with areas used for salmon farming.

Biotope and indicator species used in Sensitivity Assessment
A MarLIN Sensitivity Assessment has been compiled for Biotope 1 under the earlier designation IMX.VsenMtru (*Venerupis senegalensis and Mya truncata in lower shore or infralittoral muddy gravel*). The following indicator species are used:

Important characterizing species: *Venerupis senegalensis* (Bivalvia)

Important other species: *Mya truncata* (Bivalvia), *Littorina littorea* (Gastropoda), *Arenicola marina* (Polychaeta)

Table 6 - MarLIN Sensitivity Assessment for sheltered muddy gravels

Factor	Intolerance	Recoverability	Sensitivity	Effect on species richness	Evidence/ Confidence
Smothering	Intermediate	High	Low	Decline	Low
Synthetic compounds	High	High	Moderate	Decline	Very low
Heavy metals	High	High	Moderate	Decline	High
Changes in oxygenation	Intermediate	High	Low	Minor decline	Low

Explanation
Sensitivity to smothering is assessed as 'Low' on the grounds that infaunal bivalves and polychaetes will be able to extend their burrows upwards to keep pace with deposition. Bivalve sensitivity to TBT and the relatively low tolerance of *Venerupis senegalensis* to heavy metals are used to guide the ratings for these factors. The indicator species are all considered to have a high tolerance to hypoxia.

Conclusion
The above assessment has been prepared for the biotope SS.SMx.Imx.VsenAsquAps, but it can be regarded as also generally applicable to SS.SMx.Imx.SpavSpAn. However, the assessment does not specifically consider the potential impacts of salmon farm discharges, and this respect the conclusions of Section 7.5 are likely to apply. Examples of the Sheltered Muddy Gravels habitat directly receiving solid waste deposits from a salmon farm are likely to suffer severe impacts resulting from organic enrichment and deoxygenation. At greater distances from the point source, a gradational community response of the type defined by Pearson and Rosenberg (1978) is probable. Field studies to date do not give grounds to expect additional impacts from sediment-bound contaminants such as anti-parasite compounds, but effects on crustacean infauna cannot be ruled out.

1.5.7 Sublittoral sands and gravels

Habitat description
A habitat category covering a broad range of sublittoral sediments. Found in a wide variety of physical settings, from very sheltered (sea lochs) to highly exposed (open coast). Fauna in coarse, mobile sediments may be very sparse, but much more diverse communities occur in deeper water or more sheltered conditions. An epifaunal turf of hydroids, bryozoans and anemones may be found at the sediment surface, with a diverse infauna of bivalves and polychaetes in the sediment.

JNCC biotopes included in habitat
Over 30 biotopes are listed under Sublittoral coarse sediment (range cobble – muddy sand) in the current JNCC Habitat Classification. The JNCC website (http://www.jncc.gov.uk/MarineHabitatClassification) should be consulted for the full list.

Distribution in Scotland
A diverse spectrum of sedimentary environments is included within this UKBAP Habitat and as a consequence there are many Scottish records particularly from the west coast, Western Isles, Orkney and Shetland.

Occurrence in areas used for salmon farming
The coarser (cobble to coarse sand) substrata included within this category will mostly be found in more exposed, open-coast areas but with some examples in sea loch entrance channels and tidal rapids. The finer sands and muddy sands characteristic of more tranquil conditions will occur with greater frequency in enclosed sea loch basins, with consequently higher overlap with salmon farming activity.

Biotope and indicator species used in Sensitivity Assessment
MarLIN Sensitivity Assessments are not available for any of the biotopes included under this Habitat category. However, since the category comprises sediment biotopes characterized by infaunal invertebrates with variable representation of sessile epifauna, the assessments compiled for biotopes in the Deep Mud (Section 7.5) and Sheltered Muddy Gravels (Section 7.6) categories should be generally applicable.

Conclusion
Organic enrichment and deoxygenation resulting from sustained deposition of solid waste will have severe impacts on all biotopes in the 'Sublittoral Sands and Gravels' Habitat. The speed and degree of impact will be related to local hydrodynamics, with greater effects in more quiescent settings. Far-field effects of dissolved or sediment-bound contaminants are not predicted from the available field evidence but cannot be ruled out completely.

1.5.8 *Modiolus modiolus* beds

Habitat description
Beds of the horse mussel *Modiolus modiolus* on mixed sediments in the shallow sublittoral, often in moderately tide-swept conditions. Rich associated biota of algae, sessile and mobile invertebrates (Mair et al. 2000).

JNCC biotopes included in habitat
Four biotopes characterized by *Modiolus modiolus* beds are currently recognized:

1. SS.SBR.Smus.ModT, *Modiolus modiolus beds with hydroids and red seaweeds on tide-swept circalittoral mixed substrata.*
2. SS.SBR.Smus.ModMx, *Modiolus modiolus beds on open coast circalittoral mixed sediment.*
3. SS.SBR.Smus.ModHas, *Modiolus modiolus beds with fine hydroids and large solitary ascidians on very sheltered circalittoral mixed substrata.*
4. SS.SBR.Smus.ModCvar, *Modiolus modiolus beds with Chlamys varia, sponges, hydroids and bryozoans on slightly tide-swept very sheltered circalittoral mixed substrata.*

Distribution in Scotland
Modiolus biotopes are widespead along the Scottish west coast, in Shetland, and to a lesser extent, Orkney. Occurrence on the east coast is very limited (Mair et al. 2000). Of the biotopes listed above, Biotope 2 (ModMx) is known mainly from the Irish Sea, with one record in Shetland and a possible occurrence in Orkney. The other three biotopes are more common at sites along the west coast and in Shetland, with Biotope 3 (ModHas) being the most frequently recorded.

Occurrence in areas used for salmon farming
Many of the known occurrences are in west coast sea lochs or Shetland voes, areas of prime importance to the salmon farming industry.

Biotope and indicator species used in Sensitivity Assessment
A MarLIN Sensitivity Assessment has been compiled for the biotope SS.SBR.Smus.ModT, using information on the Key Structural species *Modiolus modiolus* and the following associated species;

Important characterizing species: *Alcyonium digitatum* (Anthozoa), *Ophiothrix fragilis* (Ophiuroidea)

Important functional species: *Echinus esculentus* (Echinoidea)

Important other species: *Delesseria sanguinea* (Rhodophyta)

Table 7 - MarLIN Sensitivity Assessment for *Modiolus modiolus*

Factor	Intolerance	Recoverability	Sensitivity	Effect on species richness	Evidence/ Confidence
Smothering	Intermediate	Low	High	Decline	Low
Synthetic compounds	High	Very low	Very high	Major decline	Very low
Heavy metals	Low	High	Low	No change	Very low
Changes in oxygenation	Intermediate	High	Low	Decline	Low

Explanation
The ‘Low’ or ‘Very Low’ ratings for Evidence/Confidence in the above table reflect the lack of available information on the environmental tolerances of *Modiolus modiolus.* There are no published studies relating to the impact of salmon farming activities on these biotopes, so inferences must be drawn from other habitats and species. Horse mussels, and their associated biota, are considered sensitive to heavy siltation, such that direct deposition of organic waste from a fish cage would have serious adverse effects. High sensitivity to synthetic compounds is inferred from the known responses of the better-studied *Mytilus edulis*, but as noted in Section 5.3 there is currently no evidence of any adverse effects of the anti-parasite chemicals currently discharged from Scottish salmon farms. Mussels, including *Modiolus modiolus*, are considered to have a high tolerance to many heavy metals. *Modiolus modiolus* has a high tolerance to hypoxia, although some of the associated species are more sensitive. However, with respect to salmon farm impacts, oxygen depletion would usually be associated with the smothering effects of settling organic waste, greatly increasing the likelihood of mortality.

Conclusion
The above assessment relates specifically to one of the biotopes characterized by *Modiolus modiolus* beds, but there is no reason to think that the responses of the other three biotopes would differ greatly. The most common *Modiolus* biotope in Scotland (SS.SBR.Smus.ModHas) is found in more sheltered, lower-energy conditions than the other three. Reduced water exchange would probably lead to an increased susceptibility to impacts associated with salmon farm discharges.

1.5.9 *Limaria hians* beds

Habitat description
Mixed muddy gravel and sand with beds or byssal ‘nests’ of the bivalve *Limaria hians*. Typically found in tide-swept narrows at the entrances or sills of sea lochs and rich in associated invertebrate fauna (Hall-Spencer and Moore 2000). Beds in shallow water may also support a range of algal species.

JNCC biotopes included in habitat
The habitat is defined by the single biotope SS.SMx.Imx.Lim, *Limaria hians beds in tide-swept sublittoral muddy mixed sediment.*

Distribution in Scotland
Current status uncertain, but records exist from the Clyde Sea, Kintyre, and from a number of west coast sea lochs including Lochs Broom, Linnhe and Sunart (Howson et al. 1994). Not recorded from the Western Isles, Orkney or Shetland.

Occurrence in areas used for salmon farming
The known occurrences of the habitat in west coast sea lochs mean that potential impacts of aquaculture must be considered.

Biotope and indicator species used in Sensitivity Assessment
The nominate biotope is used in Sensitivity Assessment. *Limaria hians* was used as the single indicator species (Key structural species). The biology of the following associated species was also taken into account:

Hydrozoa: *Nemertesia ramosa*
Anthozoa: *Alcyonium digitatum*
Bryozoa: *Bugula* spp.
Ascidiacea: *Clavelina lepadiformis, Ciona intestinalis*
Echinodermata: *Echinus esculentus, Asterias rubens*

Table 8 - MarLIN Sensitivity Assessment for *Limaria hians* beds

Factor	Intolerance	Recoverability	Sensitivity	Effect on species richness	Evidence/ Confidence
Smothering	Intermediate	High	Low	Decline	Low
Synthetic compounds	High	Low	High	Major decline	Low
Heavy metals	Low	Very high	Very low	Minor decline	Very low
Changes in oxygenation	Insufficient information	Not relevant	Insufficient information	Insufficient information	Not relevant

Explanation
The 'Low' or 'Very low' confidence ratings in the table above reflect the scarcity of detailed information on the environmental sensitivity of *L.hians.* Recent interest in conservation of the biotope has been driven more by concerns about physical damage by trawling/dredging rather than the impacts of aquaculture (Hall-Spencer and Moore 2000). As a benthic suspension-feeder, *L.hians* is likely to be adversely affected by heavy deposition of sediment, although the tide-swept conditions favoured by the species offer some protection from this form of impact. The MarLIN assessment notes a likely sensitivity to TBT, but no information is available on the effects of heavy metals. No assessment has been made for the effects of hypoxia, but the preference of *L.hians* for areas of strong tidal currents make exposure to low-oxygen conditions unlikely.

Conclusions
There is very little relevant information available for this biotope, and assessment of sensitivity to salmon farm discharges must be based largely on inferences drawn from the preferred habitat conditions. Fish cages are not usually sited in sea loch entrance channels or in tidal narrows, so that direct exposure to sedimenting organic waste is unlikely. No evidence exists for or against sensitivity to anti-parasite chemicals. The conclusions of Hall-Spencer et al (2006) that maerl beds suffered serious adverse impacts from salmon farms even in strongly tidal conditions are relevant to *Limaria* beds in similar settings.

1.5.10 *Ostrea edulis* beds

Habitat description
Dense beds of the native oyster *Ostrea edulis* on sheltered muddy fine sand mixed with quantities of dead shell. The clumps of oysters and dead shells may support an associated epifauna of ascidians and large tubicolous polychaetes. A turf of algal species may also be present.

JNCC biotopes included in habitat
The habitat is defined by the single biotope SS.SMx.Imx.Ost, *Ostrea edulis beds on shallow sublittoral muddy sediment.*

Distribution in Scotland
Formerly extensive but much reduced by over-exploitation. Currently known from sites in Loch Ryan (Galloway), Loch Sween and the Isle of Mull.

Occurrence in areas used for salmon farming
The rarity of this biotope means that overlap with salmon farming activity is very limited, but the location of the remaining sites in sheltered areas of the west coast means that potential impacts must be considered.

Biotope and indicator species used in Sensitivity Assessment
The nominate biotope is used in Sensitivity Assessment, with *Ostrea edulis* as the single indicator species.

Table 9 - MarLIN Sensitivity Assessment for *Ostrea edulis* beds

Factor	Intolerance	Recoverability	Sensitivity	Effect on species richness	Evidence/ Confidence
Smothering	High	Very low	Very high	Major decline	Moderate
Synthetic compounds	High	Very low	Very high	Major decline	Moderate
Heavy metals	Intermediate	Low	High	Decline	Moderate
Changes in oxygenation	Low	High	Low	Decline	Low

Explanation
As a suspension-feeder living in close contact with the substratum, *Ostrea edulis* will be unable to survive burial by rapid or continuous deposition of sediment. Much of the associated fauna is also likely to be killed, unless large enough to extend above the deposited layer. Suspension-feeders rely on processing large volumes of water to extract food particles and are therefore highly exposed to water-borne pollutants. Oysters and other bivalves are notoriously sensitive to TBT and also bioaccumulate heavy metals such as copper and zinc. Oysters are considered to be tolerant of periods of hypoxia and a rating of 'Low' sensitivity is given in the table above. However, the sustained oxygen depletion typical of areas with high organic loading would probably have much more severe effects.

Conclusions
Native oyster beds had been almost eliminated from Scottish coastal waters long before the advent of the salmon farming industry, so limiting the potential for overlap between them. From the Sensitivity Assessment it can safely be concluded that oyster beds would not survive directly beneath a fish cage, but like the serpulid reefs in Loch Creran might coexist with aquaculture within the same loch basin.

1.6 Summary of sensitivity of salmon farming to BAP habitats

The risk (sensitivity x overlap) associated with salmon farming is summarised at the end of Section 2.

2 Phase 2 – Characterisation of Scottish salmon farm sites

2.1 Introducstion

The objective of Phase 2 was to determine, on the basis of spatial overlap and sensitivity, the risk to BAP habitats from salmon farms. This was achieved by constructing an ArcGIS database that combined existing habitat databases which was then interrogated to characterise and categorise the benthic habitats that occurred in close proximity to farms. These results were then combined with the sensitivity assessment (Phase 1) to determine which BAP habitats were at most risk from salmon farms.

2.2 Methods

In order to characterise salmon farms site a number of open access data sources were used in addition to sources accessed under agreement from Scottish Natural Heritage (SHN).

2.2.1 The British Geological Survey (BGS) data

The BGS data layer consists of simple descriptions of the substratum and various combinations of 'mud', 'sand', 'shells' or 'rock' etc. The spatial coverage is excellent, extending into the upper reaches of sealochs with a spatial resolution (i.e. distance between records) that varies between a few hundred metres (e.g. Sound of Mull) to >1 km for more offshore areas. The upper part of Loch Linnhe, including Lochs Etive and Creran are not covered by this data source. ArcGIS was used to determine the closest BGS datum to each salmon farm and these data were summarised. The total scores, for each substratum type individually, were expressed as a percentage of the total. The following substratum types were recorded: mud, sand, gravel, shells, rock and stone.

2.2.2 Mapping European Seabed Habitats (MESH)

MESH is a European consortium charged with the collation and free publication of seabed maps and data into one central, accessible location. Much of the Scottish seabed is not directly mapped (in terms of sediment type) but the nature of the substratum has been inferred from a variety of data sources. The data layers were downloaded from http://www.searchmesh.net/Default.aspx?page=1953. Further information regarding these data layers is not provided here as they proved not to be useful for the purposes of this research primarily because both the actual and predicted substratum type rarely extended into the upper reaches of sealochs where a majority of salmon farms are located. This source of data was not applicable to the current research and is, therefore, not further described here.

2.2.3 Bathymetry

Bathymetry data for Scotland was provided by SeaZone (under contract from SNH). These data are supplied as an ArcGIS shapefile of contoured regions (>0, 0, 5, 10, 20, 30, 40, 50, 100 and 200 m contours).

2.2.4 Controlled Activities Regulations (CAR) reports

Salmon farming is, in part, regulated by Water Environment (Controlled Activities) (Scotland) Regulations 2005 (CAR). Companies operating farms are required to submit environmental monitoring reports as part of a periodic monitoring programme. These details are assessed by SEPA to determine if sediment quality criteria (SQC) are being met. These data are open access (and available from SEPA, Dingwall, Scotland) and include sediment descriptions at control stations (normally 500 – 2000 m from the farm depending on the site) that are chosen to reflect the 'background' or baseline sediment type in the specific situation. These surveys include a nonstandardised description of the sediment (i.e. one that ranges from 'sand' to 'muddy-sand containing shells and fragments of seaweed'). In order to standardise the descriptions (to allow collation) the data were split into the following key-words: clay, mud, sand, gravel, shells, boulders, rock, pebbles and stone. Individual records were then scored against this classification such that a site described as muddy-sand would score equally against both mud and sand. Surveys submitted from 108 sites (farms) were evaluated. These farms were considered to represent a random sample from the entire population of farms (there is no systematic bias as to the nature or locations of these farms).

2.2.5 National Biodiversity Network (NBN) Gateway

The NBN gateway http://data.nbn.org.uk/ is a single-point access gateway to a collation of data derived from a variety of publicly funded agencies (see http://www.nbn.org.uk/About.aspx). Data relevant to the current report stems from the Marine Nature Conservation Review (MNCR) and associated benthic marine data held and managed by JNCC. The data only represent records of the presence of various species – the absence of a record does not indicate that that species is not present.

The locations of the following species were downloaded: *Funiculina quadrangularis, Pennatula phosphorea* and *Virgularia mirabilis* on the basis that these species were indicative of the 'mud in deep water' BAP habitat. The presence of *Modiolus modiolus* was also downloaded as this particular species was considered to be at high risk from salmon farming activity. The proximity of farms to records of the various species was collated into four categories (<50 m, 50 – 199m, 200 – 499 m and >500 m). Comparisons between the accumulated percentage of records <200 m (in the potential zone of impact) and >500 m (considered outside any likely impact; Hall-Spencer et al. 2006) were compared to assist in the characterisation of salmon farm sites.

2.2.6 Data management and statistical analysis

Spatial data were managed using ESRI ArcMap and ArcCatalogue v. 9.2. The British National Grid (BNG) co-ordinate system was used in all analyses. Imported data layers that were not BNG were transformed using the ArcMap in-built default algorithms.

Routine statistical analysis was conducted using Minitab™ and SAS™.

2.2.7 Calculation of 'sensitivity'

A precautionary approach was adopted in assigning an overall sensitivity score (low, moderate or high) to each BAP habitat/species. Where individual species were scored (e.g the BAP habitat 'beds of *Limaria hians*'), the maximum sensitivity to smothering, elevated chemicals or changes in oxygenation (see 1.4) was used. Similarly, where the habitat consisted of several key species, the overall score for that habitat was based on the most sensitive species. The confidence in the assessment of overall sensitivity was carried from the MarLin sensitivity assessment; a lack of confidence in an assessment added to the identified risk. The sensitivity of a given BAP habitat/species was combined with the likely spatial overlap (Phase 2), and confidence in the sensitivity assessment, to generate a measure of risk where a highly sensitive species (or a species with an unknown sensitivity) with a high degree of spatial overlap was considered at the highest risk.

2.3 Results

The substratum lying underneath Scottish salmon farms was characterised using two independent sources: the BGS and salmon farm survey data. According to the BGS data mud and rock were the two most common substratum types found in closest proximity to salmon farm sites (each approximately 30%) with sand being found in close proximity to about 25% of salmon farms sites (Figure 1). The salmon farm survey data was broadly similar, indicating shelly-muds and sands as being the most common (both approximately 30%) substratum type found in close proximity to farm sites (Table 10).

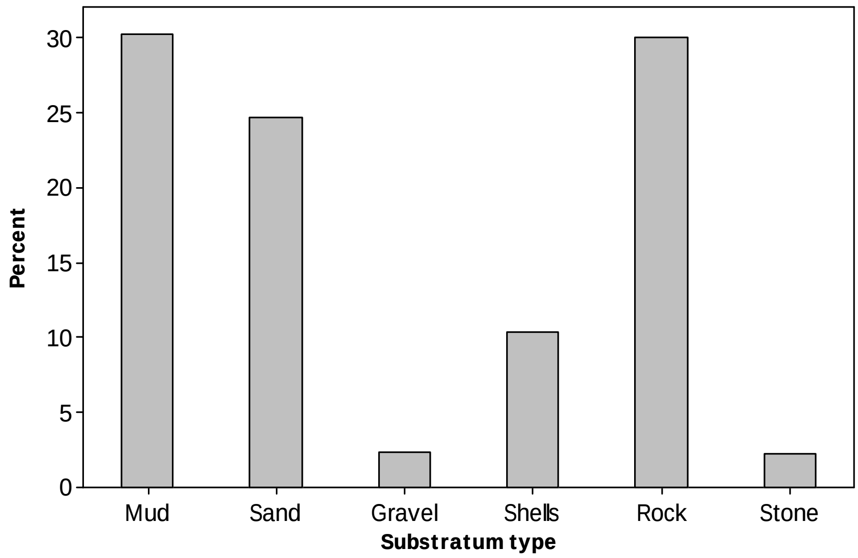

Figure 1 – Substratum type occurring in closest proximity to Scottish salmon farms (as a percentage of total). Source: BGS.

Table 10 – Ground-type characterisation from analysis of farm survey data. Source: SEPA.

Ground type	Shelly mud	fine sand	Medium/ coarse sand	Shelly sand	Stony sand	Mud (no shells)
Count	50	20	11	49	14	28
Proportion (%)	29	12	6	28	8	16

Scottish salmon farms are located over water that varied between 10 m and >100 m in depth. Approximately 23% of farms were located in water that was <20 m deep with a majority of farms being located in water between 20 and 100 m deep.

Salmon farms were commonly found in close proximity to the seapen species that are characteristic of the 'mud in deep water' BAP. For example, approximately 30% of farms are found <50 m from records of *P. phosphorea* and 20% <50 m from *F. quadrangularis* and/or *V. mirabilis.* Approximately 20% of farms were found <50 from records of the bivalve *M. modiolus*.

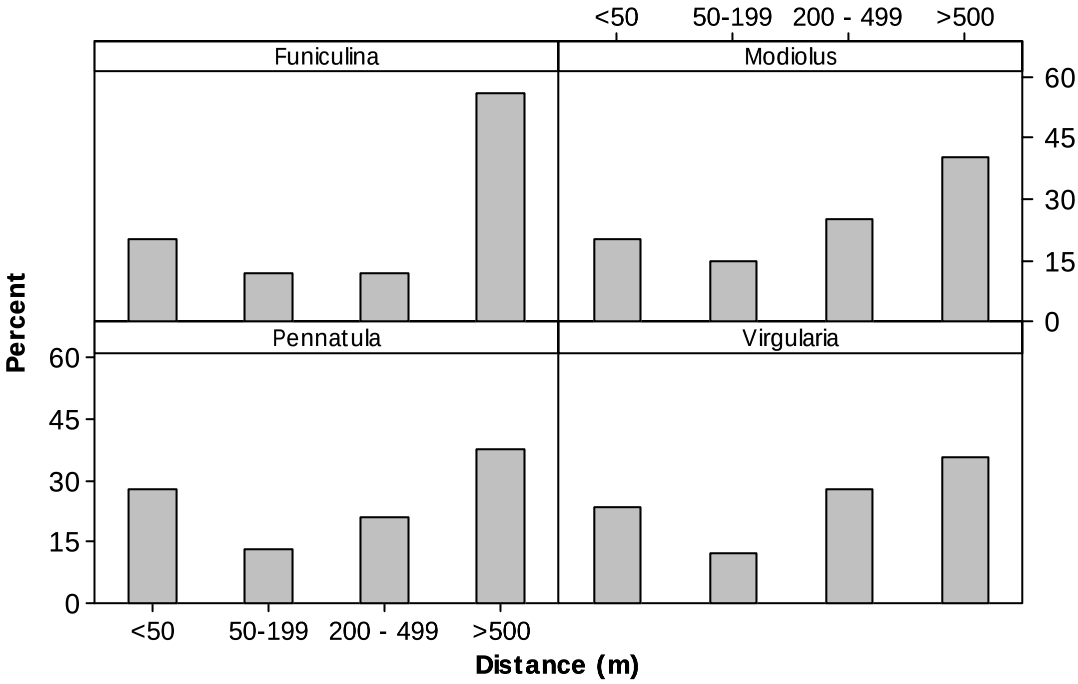

Figure 2 – The distance between recorded occurrences of *F. quadrangularis, M. modiolus, P. phosphorea* and *V. mirabilis* and the nearest salmon farm.

2.4 Conclusions

Salmon farming in Scotland occurs over ground that is typically sandy or muddy and which often contains evidence of biogenic activity (shells). Salmon farm sites are generally relatively sheltered, located in water >20 m deep and are often in close proximity to hard substrata (rock). This general picture is commensurate with the majority of the current Scottish salmon farming industry being located relatively close to shore in sheltered sealochs. The BAP habitat most closely associated with this environment is 'mud in deep water'. Such habitats are typified by species such as *P. phosphorea* and *V. mirabilis* which were frequently recorded within 200 m of current salmon farms.

Risk to particular habitats, or components in those habitats, was determined by combining sensitivity, overlap and confidence. Sensitive habitats, or habitats where confidence in the sensitivity assessment was low, where there was a high degree of spatial overlap with salmon farms, were considered at high risk (Table 11). The BAP habitat 'mud in deep water' was considered to be at high risk because very little is known about the sensitivity of key groups such as seapens.

Table 11 - Relative sensitivities (to the presence of fish farms) of BAP habitats and species, their predicted spatial overlap, confidence and subsequent risk.

BAP Habitat	Sensitivity	Overlap	Confidence	Risk
Maerl	High[1]	-	High	High
Seagrass	High	Low	High	Low
Serpulid reefs	Moderate	Low	Moderate	Low
Sabellaria reefs	High	None	Low	Low
Mud in deep water	Moderate	High	Low[2]	High
Sheltered muddy gravels	Moderate	Low	Low[2]	High
Sublittoral sands and gravels	Low[3]	Moderate	Low	Low
Modiolus modiolus beds	High	-	Low	High
Limaria hians beds	High	Low[4]	Low	High
Ostrea edulis beds	High	Low	Moderate	Low

Table 11 – notes:
Where confidence is low risk is considered higher. A hyphen indicates a knowledge gap.
1 – From Hall-Spencer et al (2006)
2 – Impacts of fish farms on muddy macrofauna extensively studied but equivalent data on the megabenthos is scarce.
3 – Considered high energy sites and dispersion of farm-derived detritus considered likely to reduce farm impacts
4 – *Limaria hians* beds are typically found in high energy environments where fish farms are generally not located but the findings of Hall-Spencer (2006), in terms of the impacts of localised accumulations of detritus, apply.

Phase 3 of this research therefore focussed on an assessment of the megafauna occurring around salmon farms located over deep-water muddy habitats.

3 Phase 3 – Impact of salmon farms on benthic megafauna

3.1 Introduction

One of the most common BAP habitats found in close proximity to salmon farms is Mud in deep-water (see Phase 2). The impact of salmon farming activity on this habitat is relatively well understood in relation to macrofauna (Pearson and Rosenberg 1978; Findlay et al. 1995; Black 1998; Cromey et al. 2002a; Read and Fernandes 2003) but much less is known about the impact on the associated megafauna, probably because this community, which is characterised by relatively large, motile and patchily distributed fauna, is relatively difficult to sample (Crawford et al. 2001).

The current licensing process for new salmon farms, or those modifying their operational tonnage, involves the use of the software DEPOMD. DEPOMOD predicts the benthic carbon flux (in the form of faecal material and waste food) to the seabed based on the site bathymetry and hydrographic regime combined with the maximum fish tonnage and stocking density of the farm (Cromey et al. 2002a; Cromey et al. 2002b). DEPOMOD then uses these benthic flux predictions to predict, semi-empirically, the resultant infaunal trophic index (ITI) (Cromey et al. 2002a). ITI is a measure of the relative proportions of benthic organisms adopting differing feeding strategies; a low ITI indicating a higher proportion of deposit or specialist feeders (indicative of organic enrichment; Maurer et al. 1999) with high values indicating a higher proportion of suspension feeders indicative of a less enriched environment. In the current (UK) context, ITI ranges between the extremes of zero (highly impacted) and 59 (background) conditions.

The organic content of sediments (whether enriched or not) is determined by the loss-on-ignition (LOI) of sediment samples at two temperatures. LOI at 250°C indicates the labile organic enrichments (typical of nutrient enhancement e.g. by fish-faecal matter) whilst LOI at 500°C indicates the amount of refractory carbon (typically cellulose or lignin) in the sediment and not necessarily indicative of organic enrichment. It can be expected that highly enriched sediments (i.e. those with a high LOI at 250 °C) will be associated with a low ITI.

The objectives of Phase 3 were to: establish the relationship between DEPOMOD predicted ITI and benthic megafauna. The focus was on deep-water muds as these were identified as showing considerable overlap with salmon farms whilst hosting megabenthic communities about which little is known (see 2.4).

The approach was to use a video camera to identify and quantify major taxa (or evidence of taxa such as burrows) at various locations around salmon farms and link any changes with the DEPOMOD predicted ITI and sediment characteristics (loss on ignition at 250 and 500 C and particle size). In this way the value of DEPOMOD for predicting the impact of salmon farms on megafaunal (as opposed to macrofaunal) communities would be assessed.

3.2 Methods

3.2.1 Site selection

Potential salmon farm sites for this survey work were restricted to those that were reasonably local (for logistical reasons) and those that had been modelled using DEPOMOD as part of the licensing process. The models used in licensing are based on the farms operating at their consented maximum biomass and, therefore, only farms in the final production stages were eligible for surveying. The following three farms met the site selection criteria: Charlotte's Bay, Creran B and Dunstaffnage Bay. These sites were all operated by Scottish Sea Farms Ltd (Equitable House, London, EC4R 9AF) and their locations are shown in Figure 3.

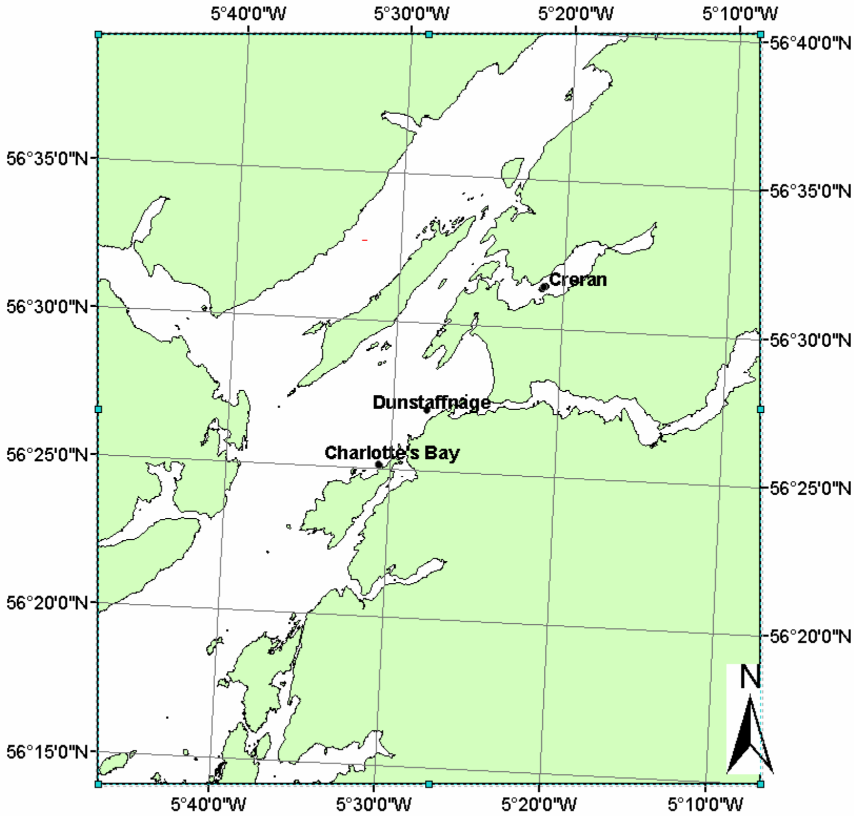

Figure 3 – Location of the three surveyed salmon farms

The Charlotte's Bay salmon farm was situated close to the shore (within 100 m) on the west of the of the island of Kererra. The site, which was exposed to the west and south, was sloping with water depths under the cages varying between about 20 (NE end) and 40 m (SW end). The Creran site was relatively unexposed and situated in the central part of the loch approximately 500 m from both shores, in water that ranged between 20 and 33 m. The Dunstaffnage site, located approximately 500 from land and exposed to the south and west, was situated on a level area of seabed of approximately 40 m in depth. More detailed descriptions of the sediments are given in the results.

The surveys (consisting of video survey and sediment sampling) were conducted between 23 July and 10 August 2009.

3.2.2 Benthic surveys (video)

A frame-mounted downward facing camera (colour, BP-L3C-High Resolution, Bowtech, Aberdeen), connected by umbilical to a surface monitor and digital recorder was used to survey areas of seabed with two 50W lights providing the main illumination. Two independent, parallel-mounted, torches with tightly focussed beams, were also attached to the camera frame (Figure 9). These torches generated spots of lights that were clearly visible on the screen thus providing a datum from which the viewable area could be calculated (Figure 10). The camera was operated such that the light spots remained (within the constraints of operation at sea) in approximately the same location giving a viewable area of approximately 1 m^2 (Figure 10).

The camera was operated by simply lowering it on a winch wire till the seabed was visible (on the surface screen). The position of the boat and camera was recorded from the onboard differential Geographical Positioning System (dGPS) and the boat and camera were allowed to drift downstream / downwind for a period of time that varied according to oncoming obstructions (mainly moorings) and the speed of the drift. This operational approach meant the camera was directly underneath the boat (no camera 'offset' calculations were necessary). Each individual camera survey was estimated to cover approximately 10 - 12 m and is an independent observation (this approach avoids the autocorrelation (non-independence) issue highlighted by Malatesta et al. 1992).

Each actual transect length was calculated using ArcGIS (based on the start/stop locations) following completion of the survey. The transect area was calculated by multiplying the transect length by 1 m^2 (viewable area). Individual transects were identified by a manually controlled numerical stamp (timestamp) that was superimposed on the recording.

The numbers and identities of prominent members of the megafaunal community associated with each transect was recorded. Species were divided into two functional groups, 'suspension-feeders' and 'predator/scavengers'. Suspension-feeders included species that were static, such as seapens and anemones whilst 'predator/scavengers' included motile, opportunistic fauna such as crabs and starfish (see 8.1).

Burrow density was recorded on the following integer scale: 0 – absent, 1 – rare/occasional, 2 – common/frequent and 3 – very common where the seabed consists mostly of burrows and mounds (compare with the three point scale used in Crawford et al. 2001). This scaled scoring systems was also applied to suspension-feeder densities where 0 - absent, 1 – up to $1m^2$, 2 – up to $2m^2$ and 3 - $>2m^2$. These two groups were then combined to form a group called sensitive species which scored between 0 and 6. To maintain consistency in data collection, the videos were interpreted by a single observer.

All survey equipment was thoroughly washed in fresh-water between surveys and then disinfected with a solution of 'Iodophor'™ at the recommended concentration, as requested by Scottish Sea Farms, as part of their biosecurity measures.

3.2.3 Sediment characterisation

Sediment samples were collected using a Craib corer (Craib 1965) (Figure 11). The top 10 mm of the core was removed and frozen within 6 hours of collection. Prior to analysis the samples were freeze-dried. The labile and refractory carbon content was determined for approximately half the sample by weight loss on ignition (LOI) at 250°C for 8h, then 500°C for 8h respectively following the standard procedure described in Loh et al (2008). Sediment samples were taken following the video survey and as close as possible to the locations of the video transects.

Particle size analysis was done using a Coulter LS230 (Beckman-Coulter, Miami, USA) to obtain mean, median and modal particle size. Prior to analysis sediment samples were suspended in 5 ml Calgon (consisting of 33g sodium hexametaphosphate and 7g sodium carbonate per litre of water) to which a further 15 ml of distilled water was added. Each sample was thoroughly mixed using a vortex mixer and then left for approximately two hours. Immediately prior to analysis the samples were sonicated in a water bath for a minimum of 20 minutes. Each sample was run three times by the Coulter LS230 to produce three estimates of the median particle size. The mean of these values was included in statistical models. The median particle size was chosen as a measure of sediment particle size as it is more robust, compared to the mean, to outliers.

3.2.4 Statistical design and analysis

For the megafaunal surveys a stratified random sampling strategy was adopted; points were randomly selected along the 10, 20, 30 and 59 ITI contours around each of the farms (using GIS). Sampling at the exact location of the random point was impossible given the restrictions of positioning the survey vessel and the presence of numerous obstructions. Obstructions included moorings, stray lines and feed-barges (and associated feed-pipes). These obstructions restricted access to the east-sides of the Charlotte's Bay and Dunstaffnage sites and limited sampling at the north side of the Creran B site. As a consequence of obstructions, the nearest possible point was sampled and the exact location of the survey equipment (camera start/stop or corer location) was manually recorded from the boat's GPS.

GIS was used to match the location of the survey to the DEPOMOD predicted ITI. The ITI gradient around salmon farms was steep meaning that there was frequently a difference in ITI between the transect start and end points. Only megafaunal data from transects where the ITI difference was <10 units were included in the statistical analysis. The ITI from the transect mid-point (mean value) and sediment characteristics from the nearest core was used in the Poisson multiple regression models.

Data were summarised using median (rather than mean) values where the distribution was not symmetrical. Where necessary relationships between predictor variables (particle size, LOI (250 and 500) were linearised prior to their inclusion in linear models, by logarithmic transformation.

Two data sets were generated, the first dataset consisted of the sediment characteristics (LOI250/500 and particle size) and associated predicted ITI. The relationship between the response variables (LOI, 250 and 500 C) and the predictor variable (ITI) was tested using normal linear regression. The model assumptions were assessed by examination of residual patterns. Model fit is given as the adjusted r^2 value (explanatory power of the model).

The second data set consisted of the megafaunal densities, the predicted ITI and the associated sediment characteristics (particle size and LOI) from the nearest core. Poisson multiple regression was used to link the response variable (sensitive species scores and predator density) to the predictors (site, LOI250/500 and ITI). Parameters were sequentially added and/or removed from the model and change in model fit (measured using chi-square) was used to determine their significance. Model fit was assessed by examination of residuals and Cooks statistics.

Multivariate analyses were conducted based on presence/absence data (to allow the inclusion of both scaled and absolute densities). The data were zero adjusted so that any totally defaunated samples were considered identical following the guidance given in Clarke et al (2006). For the sake of clarity stations were split into four ITI classes termed 15, 30, 45 and 59. The class divisions were, respectively, 0 – 22.5, 23 – 37.5, 38 – 52.5, and >53 = 59. The mean abundance for each site-class combination (three sites, four ITI classes = 12 groups) was then calculated, converted to the Bray-Curtis dissimilarity matrix and ordinated using non-metric multiple dimensional scaling.

Data manipulation and management was done using SAS (SAS Institute, USA). Simple linear regression was done using Minitab v.15 (Minitab Inc), Poisson regression was done using Genstat v.5. Multivariate analyses were done using Primer v.6.

3.3 Results

3.3.1 Sediment characterisation

In total, 117 cores were taken. The sediment at all sites can be classified as a silt (Buchanan 1984), however, the sediment at Creran B was considerably coarser than both the Charlotte’s Bay and Dunstaffnage sites (median particle size approximately 50 µm compared with approximately 20 µm for the other sites(Table 12). Conversely, overall, the median LOI at both temperatures was less at the Creran site compared with either of the other sites (Table 12). The median ITI predicted for the cores was lower (approximately 30) at the Charlotte’s Bay site compared with the other sites which were approximately the same (Table 12).

Table 12 – Summary characteristics of sediments from the three sites (Charl – Charlotte's Bay, Dunst – Dunstaffnage Bay). .

Site	Particle size (µm)	LOI (250°C)	LOI (500°C)	ITI	N
Charl	19.6 (15.1, 34.6)	4.71 (3.73, 6.44)	9.38 (8.39, 10.1)	30 (10, 54)	36
Creran	48.7 (35.7, 66.6)	3.80 (2.82, 5.59)	4.40 (3.47, 5.51)	46.0 (28, 59)	37
Dunst	18.3 (12.7, 30.3)	5.64 (4.28, 7.83)	9.01 (8.22, 9.71)	42 (11, 52)	43

The first figure given is the median with the first and third quartiles given in parenthesis. LOI – loss on ignition (with temperature given in parenthesis), ITI – infaunal trophic index, Depth – mean depth (in m), N = number of samples

The relationship between ITI and log LOI 250 was the same between all sites. The regression equation was, following removal of one outlier on the basis of its high Cook statistic:

log LOI250 = 2.02 – 0.0108 x ITI (F=23 with 1 and 114 df, P<0.001, r^2=0.161).

There was no consistent relationship between ITI and LOI 500.

3.3.2 Benthic surveys

In total 132 transect surveys were completed. Only those with good underwater visibility and where the endpoint ITIs were less than 10 (see 3.2.4) were included reducing the analysed number to 91 (33, 31 and 27 at Charlotte's Bay, Creran B and Dunstaffnage respectively). The median transect length was 11.4 m (with upper and lower quartiles being 7.7 and 11.1 m respectively).

Twenty species/groups of fauna were identified from the video images (see 8.1). In terms of counts these megafauna were dominated by the seapens *P. phosphorea* and *V. mirabilis*. Other species making a major contribution were the predator/scavengers *Asterias rubens*, hermit crabs *Pagurus spp*., the crabs *Liocarcinus* sp and *Carcinus maenas* and fish such as gobies and gadoids. Gadoids were present at Dunstaffnage as shoals 10 – 15 m from the cage edge. On many transects no megafauna were observed, particularly on those transects close to the cage edge. Multiple dimensional scaling demonstrated a clear difference between the assemblage structure between sites (based on presence/absence transformed data) with the Creran stations (Cr) clustered on the right hand side of the ordination (Figure 4). These were shown to be different to both Charlotte's Bay and Dunstaffnage assemblages (ANOSIM, R=0.807 and 0.615 respectively, both P=0.029). However, there was no pattern in the assemblage as influenced by the ITI, for example the mean Cr15 station was closer to the mean Cr59 station than it was to either the Cr30 or Cr40 stations (Figure 4).

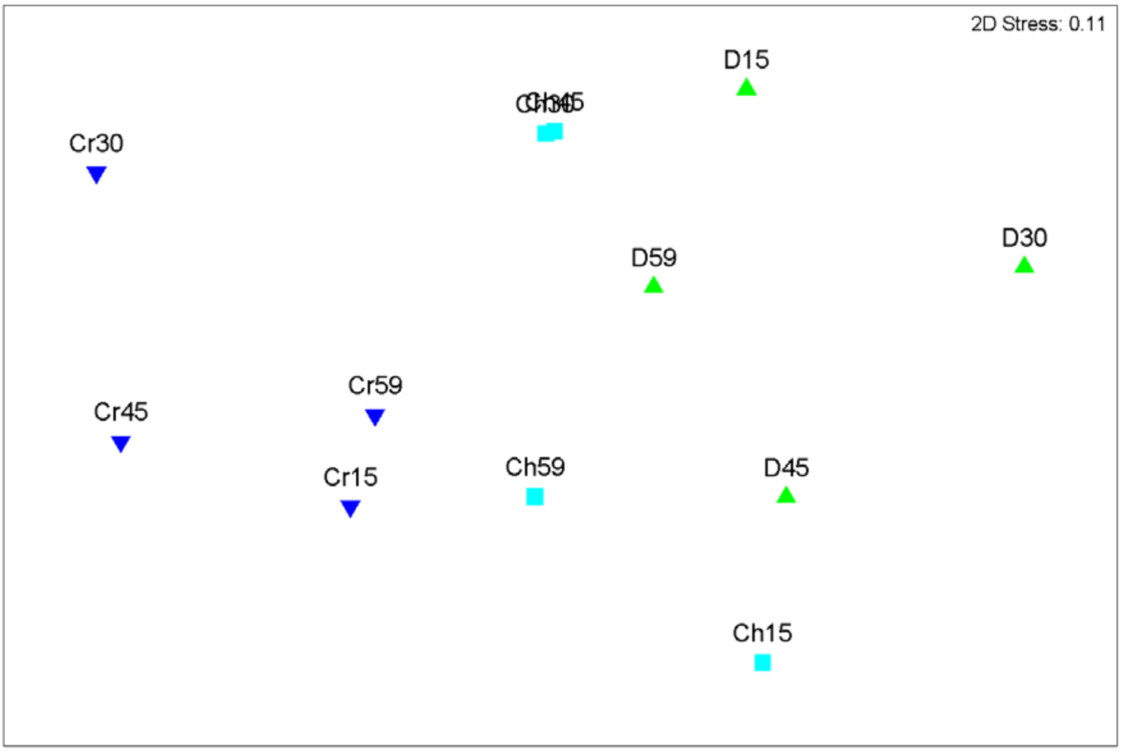

Figure 4 – MDS of site x ITI midpoints combinations. Key: Ch – Charlotte's Bay, Cr – Creran, D – Dunstaffnage. The values following the key indicate the ITI midpoint (see methods for explanation).

Combining the observed taxa into two functional groups (suspension-feeders, the combined score for suspension-feeder and burrow abundance and predators/scavengers) reveals substantial abundance differences (in additional to the taxonomic differences indicated using MDS) between the sites: at Creran B there were many more predator/scavengers and suspension-feeders than at Charlotte's Bay or Dunstaffnage (by a factor of approximately four and 16 respectively) yet burrows were nearly absent from Creran but common at both the Charlotte's Bay and Dunstaffnage sites.

Table 13 – Mean densities of megafaunal groups at the three surveyed sites

Site	Group	Mean density
Charlotte's Bay	Burrows	1.58
	Predators	0.0855
	Suspension-feeders	0.173
Creran	Burrows	0.194
	Predators	0.311
	Suspension-feeders	1.20
Dunstaffnage	Burrows	1.56
	Predators	0.0198
	Suspension-feeders	0.125

(Predators = predators/scavengers, density is given as the mean per m^2 except for burrows where it is the mean density score).

The pattern of abundance of predators as a function of mean ITI was complex and no clear pattern emerged (Figure 5) and, at the Dunstaffnage and Charlotte's Bay site, most transects contained no members of this group. There were no predator/scavengers at an ITI of less than five.

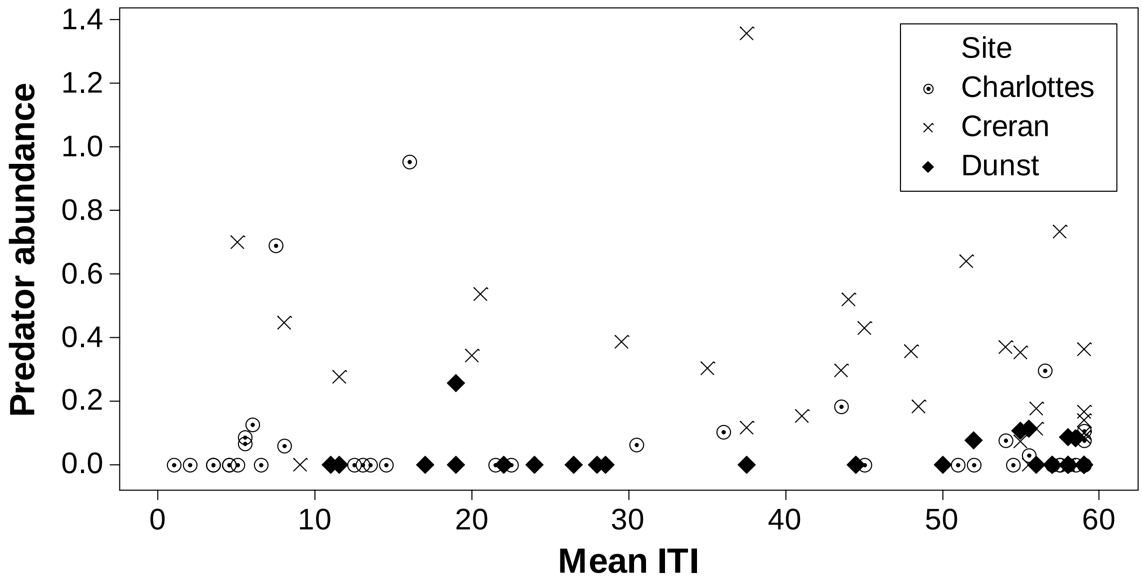

Figure 5 – Predator/scavenger abundance per transect (density, numbers per m^2) compared with mean ITI for that transect for the three sites (Dunst = Dunstaffnage Bay).

Megafaunal burrows and suspension-feeders were negatively associated but both are indicative of a non-impacted environment (Pearson and Rosenberg 1978). This means that, on some relatively non-impacted sites (i.e. high ITI) there were no burrows but numerous suspension-feeders (typically at the Creran site) whilst at others there were numerous burrows but few, if any, suspension feeders (typical of Dunstaffnage) (see 0)This natural variability made fitting a linear model relating burrowing activity or suspension feeders, on an individual basis, to ITI difficult and there was, therefore, a requirement to combine them into one group (termed 'sensitive species'). The relationship between sensitive species score and ITI was not clear, although a general trend of increased abundance score with increasing ITI, which differed between sites, can be seen in Figure 6.

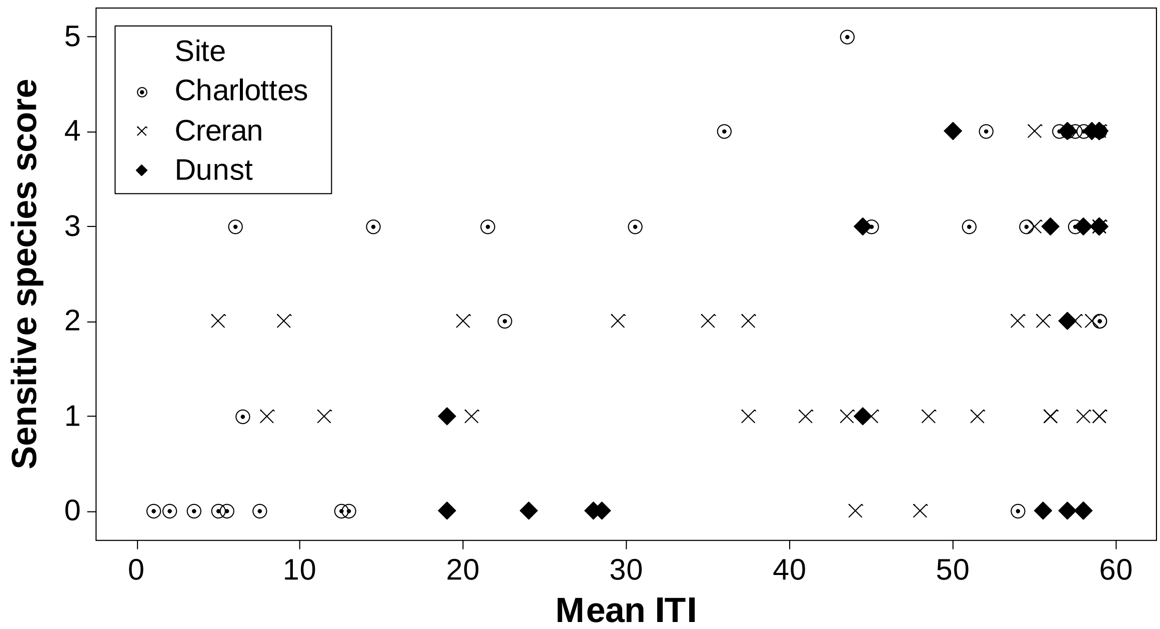

Figure 6 – Sensitive species abundance per transect compared with mean ITI for that transect for the three sites (Dunst = Dunstaffnage Bay).

Analysis of the sensitive species scores showed a significant site effect and a significant relationship with ITI. The Poisson regression equation was, for Charlotte's Bay: log (sensitive species score) = -0.129 + 0.0241 x ITI. For Creran and Dunstaffnage, respectively, the following constants should be subtracted from the regression equation: 0.483 and 0.381. The deviance ratio was10.22 with 3 and 84 df, P<0.001 and the model accounted for 23% of the total variability in the data set with 17% being attributable to ITI. No other factors (LOI250, LOI500, PSA) made a significant improvement in the model fit.

The modelled relationship between sensitive species score (excluding site) and ITI, with 95% confidence intervals (Figure 7) illustrates predicted increases in sensitive species, from a mean score of approximately 1.5 ('rare') at an ITI of 0 – 20 a score of approximately four (common) at an ITI of 59. This difference is significant (at 5%) as indicated by the non-overlap of the confidence intervals.

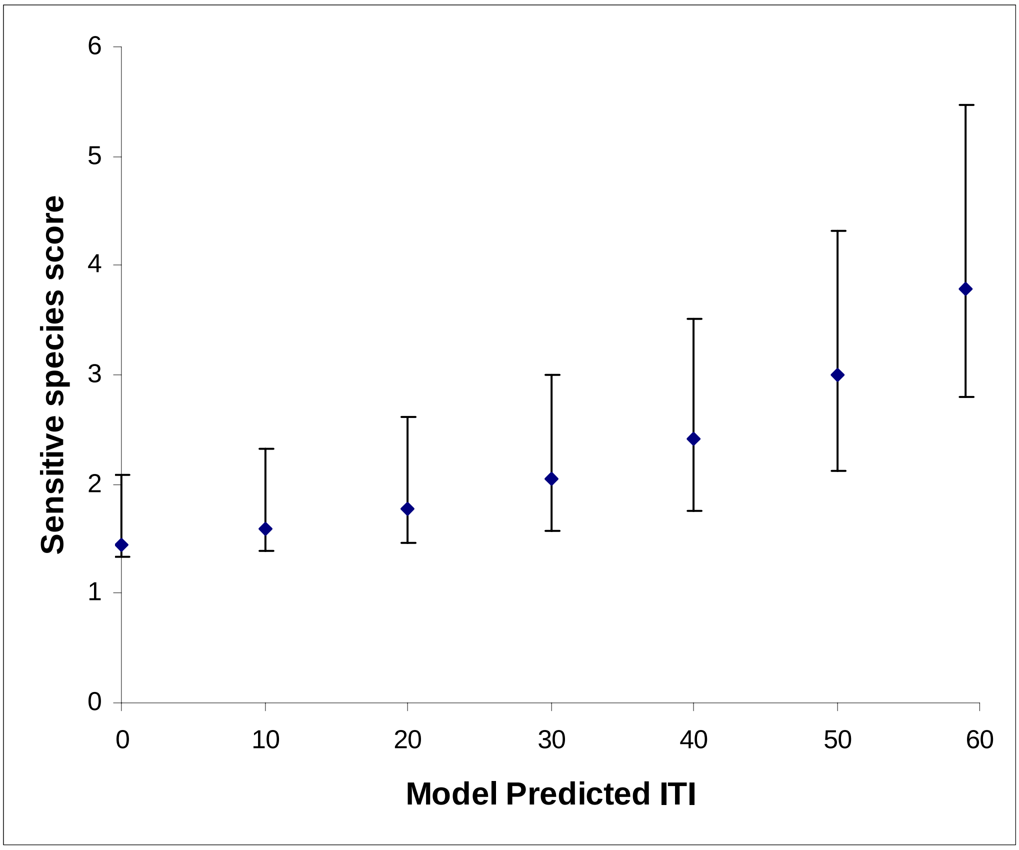

Figure 7 The modelled relationship between predicted sensitive species score and ITI (with 95% confidence interval).

3.4 Conclusions

There were three major results that arose from Phase 3.
1. There was a highly significant, negative relationship between DEPOMOD predicted infaunal trophic index (ITI) and loss on ignition (LOI) at 250°C
2. Sensitive species were positively associated with DEPOMOD predicted ITI
3. There was no discernable relationship between predator/scavenger abundance and DEPOMOD predicted ITI.

A vast majority of previous research looking at the impacts of salmon farms on the receiving environment has focussed on macrobenthic infaunal assemblages as this group is relatively easy to sample and assess. Much less was known about the impacts of salmon farms on the megabenthos, partly because megafauna are difficult to observe for a number of logistical and methodological reasons. The development and assessment of cost-effective techniques to overcome these problems was a major component of this research.

The drop-down video survey methodology described worked very well in the challenging environment (numerous obstructions and limited space) around fish-cages. The system achieved high spatial accuracy (necessary where working on steep environmental gradients) and reliability and was cost-effective enabling approximately 30 independent seabed observations in six hours. However, such survey methodology has drawbacks including the consistency of the viewable field as a consequence of varying speed and height over the ground (which depends on prevailing sea and weather conditions) and variability in underwater visibility. Converting densities to an ordinal scale, as done here for both evidence of burrowing and suspension-feeder abundance is commonly used in benthic surveys (e.g. the SACFOR scale; Hiscock 1998) including those around salmon farms (Crawford et al. 2001) and addresses the problems associated with a lack of precision in making direct counts. However, conversion to an ordinal scale is both subjective (i.e. in determining the number of classifications that are considered reasonable) and is likely to reduce the power of the result statistical analysis.

The Poisson regression model fitted the sensitive species score relatively well. The best single predictor was ITI (accounting for 18% of the variance) with a significant site effect (transects from Charlotte's Bay had, on average, a greater score than both the other sites). When ITI and site were taken into consideration none of the other predictors (LOI250/500 and particle size or their interactions) made a significant contribution to the model indicating that the predicted ITI encompasses the effects of organic enrichment and that, within site, there was no effect of particle size on sensitive species score.

Megafauna were entirely absent at the cage edge (where ITI < 5) and it seems likely that this environment is hostile to all megafaunal species. Beyond this extreme predators/scavengers became relatively common, possibly attracted to the organic detritus derived from the farm (Hall-Spencer et al. 2006). Data heterogeneity meant that the confidence intervals around the predicted relationship between ITI and the sensitive species score were quite broad. However, the statistical model indicates that at an ITI of 0 – 20 sensitive species will be rare/occasional, significantly fewer compared to their common/frequent abundance at an ITI of 59. Beyond at ITI of 5 there was no observed step-change in sensitive species score at any particular ITI, including ITI=30.

Abundance is not the only plausible indicator of the health of megafauna, particularly non-motile species such as seapens. In the current case a majority of observed seapens (*P. phosphorea* and *V. mirabilis*) looked very similar (both species erect, feeding branches held horizontally in the case of *P. phosphorea*). However, it was noted that several individuals of *P. phosphorea* located in close proximity to the Creran site cage-edge were non-erect with the feeding arms drawn in. It is unknown whether this is a stress-response or a normal part of their behaviour but it was not observed at any other sites.

Analysis of the data also posed numerous challenges. These are due predominantly to the zero inflation (numerous zero counts) of the data. Increasing the transect length would be one mechanism by which the zero-count issue could be addressed but this would then increase the undesirable likelihood of the transect encompassing a greater range of predicted ITI and would reduce the scope of a single core sample being representative of the transect. Megafaunal are often patchily distributed (Langton and Robinson 1990) particularly seapens (Greathead et al. 2007) with recruitment and survivorship likely to be dependent on numerous factors other than the proximity of a salmon farm. The sites selected here extended to around the 59^{th} ITI contour (in order to sample across the entire range of ITI). However, at the peripheries of salmon farms (where the ITI=59) there can be considerable fishing effort, particularly trawling for *Nephrops norvegicus* which is likely to reduce the abundance of both burrows and seapens (Watling and Norse 1998). The absence of sensitive species, at sites furthest from the fish-cages (and therefore relatively unimpacted by the salmon farm) may, therefore, be attributable to fishing damage. This could not quantified because of a lack of information on local fishing practices and is an additional factor that may account, at least in part, for the relatively poor predictive power of the statistical model. The only way to better describe the random and non-random elements in this population distribution is to increase the number and complexity of surveys. We believe, in concurrence with Crawford et al (2001), that the use of megabenthic camera surveys is unlikely to be a cost-effective method of monitoring the extent of salmon farm impacts.

4 Knowledge gaps

This research highlighted some important knowledge gaps concerning the environmental consequences of salmon farming. In respect of megafauna specifically, these aspects should take priority in further research (points (a) and (b)) and could, at least in part, be addressed by implementation of point (c).

(a) The extent to which rocky habitats (notably the sides and shallow areas in sealochs) overlap with salmon farms should be further investigated.

(b) Further research into the chronic and acute effects of salmon farms, on seapens and *Modiolus modiolus* , should be investigated. This should be done through a controlled transplantation experiment and include measures of fitness and/or stress. In the case of *M. modiolus* this should be accompanied by an assessment of any associated biodiversity change.

(c) We recommend the standardisation of existing statutory reporting from industry to SEPA. Such a standardisation would increase the research value of future observations made by salmon farmers in regulatory compliance and incur no additional cost.

The following, more general concerns should also be addressed:

(a) The fate and behaviour of metals released via salmon farms, their possible release into the water column during periods of fallowing, the degree of uptake by marine organisms and the potential for biomagnification up the food chain needs further investigation

(b) The potential for acoustic methods for the mapping the distribution of sediments and features e.g. burrows around salmon farms should be evaluated.

5 Management implications

5.1 Monitoring change and its meaning – general discussion

During this research a number of meetings were hosted by SAMS with industry, conservation and regulatory representatives (as part of the SARF review process). During these meetings the concept of ‘experimental power’ was discussed at length in relation to monitoring impacts (this concept is covered in many standard statistical texts e.g. Sokal and Rohlf 1995; Underwood 1997; Quinn and Keough 2002) and it is worth summarising those discussions, and their implications, here.

Any anthropogenic development, such as a fish-farm, will have an impact on the receiving environment which decreases with increasing distance. Experimental power is a measure of the probability of a series of observations (e.g. the Phase 3 of this research) of detecting that impact, in terms of finding a statistically significant change. Finding this change is a function of the number of observations/samples taken and the degree of, and variability in, the change that is actually occurring. The implication of this is a small sample size is likely to result in the acceptance of the null hypothesis (usually of no impact occurring) and that, without any indication of experimental power, this might be perceived as being evidence that no impact was occurring (Gigerenzer 2004). Conversely, a sufficiently large sample size will detect very minor (and potentially unimportant) changes (Gigerenzer 2004).

In terms of managing the impacts of fish-farms, and complying with statutory obligations, this has a number of implications as the concept of there being zero change around a development is not valid (one implication is that detecting a potential environmental change is a function of the sampling budget!). It is the ecological relevance of any change that is important, not just whether a change is occurring. Gibbs (2007) recently stated (of shellfish mariculture) that the ecological carrying capacity is the ‘level of culture that can be supported without leading to significant changes to ecological processes, species, population or communities in the growing environment'. Setting this acceptable limit is challenging and would, firstly, necessitate a clear definition of the conservation objectives including the spatial scale at which these objectives should be applied (e.g. sealoch or bay within sealoch). Setting acceptable limits in this way (e.g. a proportion loss compared with the background population within the spatially defined area) would require thorough understanding of the species' ecology including dispersal and recruitment mechanisms and recovery rates and be related to an agreed recovery period that would enable the population to return to an acceptable level. Defining these acceptable limits (in space and time and the nature of any change) is still a source of debate in the scientific community (Keely et al. 2009).

5.2 Management implications of SARF036

The literature review highlights three BAP habitats that are considered likely to be at highest risk from fish-farms. These are maerl and beds of *L. hians* and *M. modiolus.* Our understanding of the impacts of fish-farms is currently insufficient to enable us to make recommendations regarding regulation of fish-farms in relation to these habitats, particularly in respect of delineating an acceptable degree of impact (see 4and 5.1).

Our research indicates that megafauna are not, on their own when observed using camera, a particularly sensitive indicator of the effects of salmon farms on the benthic environment. This was primarily because of their inherently patchy nature and (naturally) low abundance (see Crawford et al. 2001). However, whilst it was clear that elements of the deep-water muddy BAP megabenthos, such as seapens, were severely depleted at the farm boundary fish-farming did not appear to be responsible for the large scale eradication of species such as *P. phosphorea*.

In terms of protecting benthic megafauna, such as seapens, addressing other sources of impact, such as trawling damage, may yield a greater degree of conservation value (e.g. Watling and Norse 1998).

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8 Annexes

8.1 List of fauna and functional group classification.

Table 14 –Total faunal counts at Charlotte's Bay, Creran B and Dunstaffnage sites showing the numerical dominance of seapens (*P. phosphorea* and *V. mirabilis*) and scavengers (crabs and starfish).

Taxon	Charlotte's Bay	Creran B	Dunstaffnage	Classification
Antedon bifida	0	2	0	F
Asterias rubens	1	44	0	P
Buccinum undatum	0	1	0	P
Carcinus maenas	5	11	2	P
Cerianthus lloydii	4	0	1	F
Funiculina quadrangularis	4	0	0	F
Gadoid	5	5	Shoals	P
Goby	4	15	1	P
Pagurus spp.	0	29	2	P
Liocarcinus depurator	11	10	5	P
Metridium senile	2	4	2	F
Munida rugosa	0	1	0	P
Nephrops norvegicus	1	1	0	P
Pachycerianthus multiplicatus	0	1	0	F
Pennatula phosphorea	20	204	42	F
Psolus phantapus	0	4	0	F
Aequipecten opercularis	0	1	0	F
Raja spp	1	0	0	P
Goneplax rhomboids	1	0	2	P
Virgularia mirabilis	27	387	0	F

The classification of various organisms into either suspension-feeders (F) or predator/scavengers (P) is also shown.

8.2 Plots of burrows and suspension feeders v. Mean ITI.

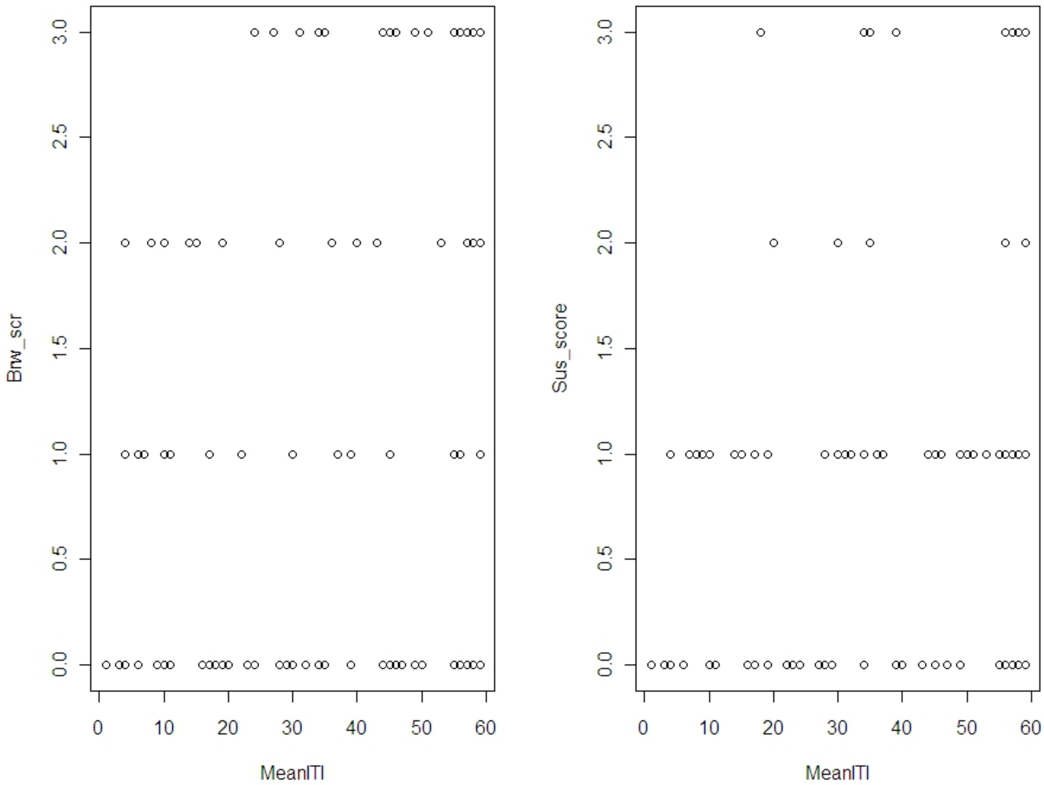

Figure 8 – Burrow score (Brw_scr, left) and suspension feeder scores (Sus_score, right) against the mean ITI (MeanITI).

8.3 Figures

Figure 9 –The camera being deployed (Dunstaffnage site) over the stern of the RV Seol Mara. Note the downward facing, parallel mounted torches (yellow) on the camera frame.

Figure 10 – Pennatula phosphorea at the Creran B site, associated with an ITI of 59 (unimpacted site). The viewable area is approximately 1 m^2. The two dots of light were generated by the parallel mounted torches and indicate a distance of 0.6 m.

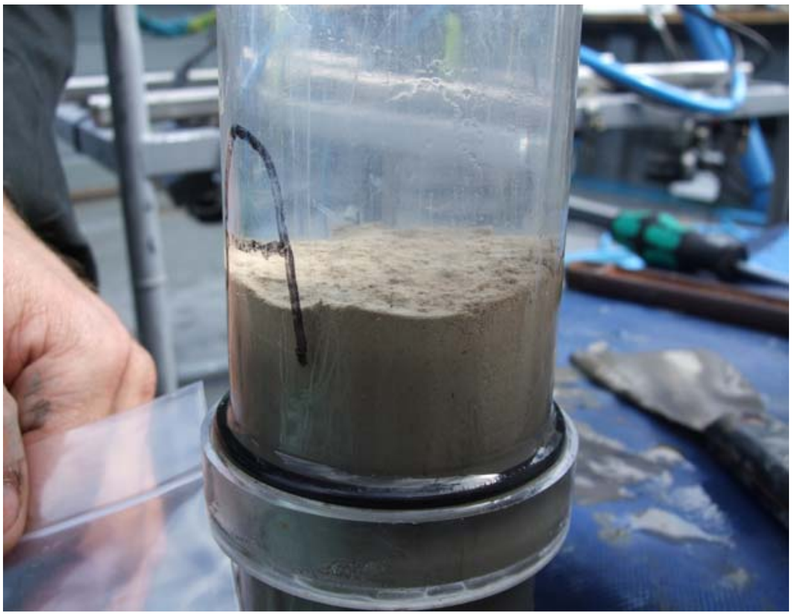

Figure 11 – A typical core from a non-impacted part of the Dunstaffnage site. The top 10 mm was removed for sedimentary analysis (LOI250 and 500 and particle size analysis).

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